SUMMER ROOST SELECTION AND ROOSTING BEHAVIOR OF *MYOTIS SODALIS* (INDIANA BAT) IN ILLINOIS

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Prepared by
James E. Gardner, James D. Garner*, and Joyce E. Hofmann
Illinois Natural History Survey/Illinois Department of Conservation*

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ABSTRACT

From May 1986 through September 1989 more than 326 *Myotis sodalis* were discovered roosting in 48 different trees in eight Illinois counties. Thirty-five roosts were documented within the Fishhook Creek study area, Pike and Adams counties, Illinois. Twelve tree species were used as roosts: *Ulmus rubra* (slippery elm), *Quercus rubra* (northern red oak), *Carya ovata* (shagbark hickory), *Acer saccharinum* (silver maple), *Populus deltoides* (cottonwood), *Quercus stellata* (post oak), *Carya cordiformis* (bitternut hickory), *Sassafras albidum* (sassafras), *Acer saccharum* (sugar maple), *Quercus alba* (white oak), *Quercus imbricaria* (shingle oak), and *Ulmus americana* (American elm).

Myotis sodalis typically roosted beneath the exfoliating bark of dead trees (41 of 48 roosts). Other roost sites were beneath the bark of living trees (n=4) and in cavities of dead trees (n=3). Roost trees were found in upland situations and within floodplains; 26 were located in areas where livestock were grazing. Single roost trees were found in a palustrine wetland, a heavily grazed ridgetop pasture containing a few scattered dead trees, a partially wooded swine feedlot, and a clear-cut encircling a segment of a perennial stream. Bats selected roosts near to intermittent streams and away from paved roads.

Some roosts within the Fishhook Creek study area were used by *M. sodalis* during successive summers, thereby documenting their significance as traditional roost sites. The recapture of a reproductively active adult female in the Fishhook Creek study area two years after she had been banded as a juvenile indicated site philopatry. Several males were also recaptured within the Fishhook Creek study area in successive summers.

Microclimate studies of roost sites revealed that sites exposed to intense solar radiation during midsummer may develop temperatures potentially lethal to *M. sodalis*. These same roost sites, however, may be entirely suitable in spring and early summer. Trees moderately shaded from intense radiation and adequately ventilated may be suitable as roost sites throughout the spring and summer.

The natural attrition of roost trees within the Fishhook Creek study area indicated that the availability of some tree species may be short (<4 years). Tree removal for harvest or land clearing is the primary threat to the summer roosts of *M. sodalis*; however, selective harvest of living trees within the Fishhook Creek study area did not directly alter summer roosting habitat.

CONTENTS

CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES
(concluded)

LIST OF TABLES

INTRODUCTION

The distribution, status, and roost requirements of winter populations of the federally endangered (U.S. Congress, 1973) *Myotis sodalis* (Indiana bat) are well known (Hall 1962; Cope and Humphrey 1977; Humphrey and Cope 1977; Humphrey 1978; Clawson *et al.* 1980; LaVal and LaVal 1980; Thomson 1982). National legislation and comprehensive management plans developed by federal and state agencies have been implemented in efforts to protect major hibernacula used by this species (Lera 1978; LaVal and LaVal 1980; U.S. Fish and Wild. Serv. 1983; Clawson 1987; Clawson and Titus 1989). Nevertheless, very few colonies of *M. sodalis* have been investigated outside of caves and thus their summer (non-cave) roosts are poorly known. According to Humphrey *et al.* (1977), the greatest mystery in the natural history of the Indiana bat is the location of its summer habitat; consequently no range-wide management plans identify and protect that habitat. At present, only roosts (defined as dead trees with exfoliating bark) that are actually occupied by bats during the summer maternity season are protected during that season by federal law.

The first reported nursery colony of *M. sodalis* was discovered in August 1971 in a dead *Ulmus americana* (American elm) in Wayne County, Indiana (Cope *et al.* 1974). This colony was discovered after their roost tree had been destroyed during agricultural clearing. Three years later, another nursery colony was located by Humphrey *et al.* (1977) in a dead *Carya cordiformis* (bitternut hickory) in the same general area. Individuals from this roost also used an alternate roost under the naturally exfoliating bark of a living *Carya ovata* (shagbark hickory), located 30 m away. Dr. J. O. Whitaker, Jr. (pers. comm.) identified eleven dead adult female *M. sodalis* collected on September 8, 1984, in Knox County, Indiana, from a dead *C. ovata* after the tree had been felled. Another summer colony of *M. sodalis* was reported in the hollow branch of a riparian tree destroyed by a utility company during right-of-way clearing (Humphrey *et al.* 1977). Immature males have been captured from beneath a concrete bridge and from beneath the bark of an "old" tree in Indiana (Mumford and Cope 1958).

The above information, however, is insufficient to formulate strategies for the protection of *M. sodalis* summer maternity populations and their essential habitats. Roost sites are necessary for social interactions, for protection from the weather and predators, and for successful parturition and recruitment of young. For these reasons, this project undertook to describe ecological aspects of summer roosts, particularly maternity roosts, of *M. sodalis* in Illinois.

Within the past 20 years, technological advances in radio telemetry equipment have made radio-tracking an important research method for ecological field studies of bats.

Researchers have successfully used miniature radio transmitters attached to bats to locate diurnal roosts and to examine temporal and spatial aspects of foraging activity (e.g. Bradbury 1977; Thomas and Fenton 1978; Heithaus and Fleming 1978; Morrison 1978, 1980; McCracken and Bradbury 1981; Brigham 1983; Fenton *et al.* 1985; Tidemann *et al.* 1985; Barclay 1985; and Brigham and Fenton 1986). Recently, radio transmitters were used to study roosting behavior, the selection of roost sites, and fidelity to roost sites (Barclay *et al.* 1988; Wai-Ping and Fenton 1989).

Although radio transmitters are lighter than ever (0.72-0.82 g), the ability of such small (5-9 g) aerially foraging species as *M. sodalis* to carry loads approaching 15% of their body weight deserves serious consideration. Aldridge and Brigham (1988) demonstrated that a load >5% of a bat's mass decreases maneuverability and foraging efficiency and increases energy costs. Such increases in mass may force bats to forage for longer periods and only within sites having less clutter (echoes returning from objects other than prey). Stebbings (1982) attached transmitters equivalent to 12% of the body weight on *Rhinolophus ferrumequinum* (horseshoe bat) weighing from 17 to 27 g. Tidemann *et al.* (1985) found that vespertilionids could carry up to 25% of their body weight. Pregnant *M. sodalis* foraged and selected roosts while carrying embryos that had gradually increased their weight by as much as 28% (based on adult females captured in Illinois from 1985 through 1989). Female *M. sodalis* also proved capable of flying with partially grown young weighing from 2.0 to 3.8 g (Humphrey *et al.* 1977), however, they did not forage while carrying the young.

Despite evidence that the "normal" foraging behavior of a bat may be affected by the weight of a transmitter attached, radio-tracking offered a dependable method for studying the summer roosting ecology of *M. sodalis*. Our attempts to locate bats roosting in dead trees by searching for guano on the ground and on nearby vegetation were ineffective. Potential roost trees were also scanned with a bat detector while creating a disturbance. More than 2,000 trees in Illinois were examined in this manner from 1980 through 1989; only one *M. sodalis* roost tree was discovered. Our radio-tracking studies revealed that bats do not dependably emit signals when their roost tree is disturbed.

During our study, *M. sodalis* were able to maneuver successfully with an attached radio transmitter equal to 8% to 14% of their body weight. Roost selection and roosting behavior of nonradio-tagged and radio-tagged *M. sodalis* were compared to determine if roost selection or roosting behavior were affected by radio-tagging.

METHODS

Bat Capture

Bats were captured with black, monofilament Japanese mist nets (38-mm mesh) ranging in length from 5.5 m to 18.3 m. Mist nets of equal length were stacked vertically (6.1 m to 9.1 m in height) with the end loops secured to a rope and pulley system suspended on pairs of interlocking metal masts (Gardner *et al.* 1989). Mist nets were positioned adjacent to roosts, over stream corridors and other types of flyways, and beneath forest canopies.

Data recorded for each bat captured included location, date, time of capture, height (m) in net above water (ground), sex, age (adult or juvenile), weight (g), and reproductive condition (females = nonreproductive, pregnant, lactating, post-lactating; males = scrotal or nonreproductive). Juveniles were distinguished from adults by smaller overall size and incomplete ossification of the epiphyses. Males were considered reproductively active (scrotal = functional testes) when enlarged and fully distended epididymides were visible in pigmented sheaths in the uropatagium. Females were determined to be either lactating or post-lactating by teat examination. Pregnancy was diagnosed by abdominal palpation with care taken not to mistake a food-distended stomach for a fetus. All *M. sodalis* were banded (males on right wing, females on left wing) with sequentially numbered, size XCL plastic bands (A. C. Hughes, London, England) of various colors and immediately released at the site of capture.

Radiotelemetry Equipment and Tracking

Efforts to capture and band *M. sodalis*, and subsequent searches for their roosts were conducted statewide; however, radio-tracking was employed at a limited number of sites. When *M. sodalis* were radio-tagged, series BD2A radio transmitters with frequencies ranging from 172.0 to 173.0 MHz were used (Holohil Systems Ltd., Ontario, Canada). These rectangular-shaped transmitters measured 12 mm X 8 mm X 4 mm with an 11-cm whip antenna. Pre-attachment transmitter weights ranged from 0.72 to 0.82 g. Transmitters were attached with non-toxic skin-bond cement (Pfizer Hospital Products Group Inc., Largo, Florida) to the mid-sagittal dorsal surface midway between the scapulae and the external origin of the tail. At this position, hair was clipped from an area of skin large enough to accommodate the transmitter.

Model TRX-1000S tracking receivers (Wildlife Materials Inc., Carbondale, Illinois) were used to locate bats in conjunction with collapsible series F172-3FB three-element Yagi antennas (AF Antronics, Inc., White Heath, Illinois). Under optimal conditions (clear nights with dry vegetation), line-of-sight signals were received from distances up to 3 km over rolling, partially forested terrain; however, a diurnal receiving range of ≤1 km was more common. After a signal had been tracked to its source and the roost tree identified, the exact site (≤ 1-m segment) of the radio-tagged bat beneath the bark or in a cavity was determined. Distorted signals could be heard when the receiving antenna passed within 3-4 cm of the transmitter's antenna. In addition, a directional loop (null-peak) antenna Model L216-SM (AF Antronics, Inc., White Heath, Illinois) was used for pinpointing radio-tagged bats beneath bark and for recovering transmitters that had become detached from the bat.

Fixed-station tracking was conducted on selected bats to determine their foraging range. Signals were monitored with a null/peak antenna configuration from each of three stations positioned in triangular fashion surrounding the foraging area of the bat. Bearings were taken simultaneously and analyzed with TELEMPC (University of Missouri and Missouri Department of Conservation, Columbia, Missouri) computer software. The geometric center of a bat's foraging range was calculated automatically by TELEMPC.

Roost Analysis and Habitat Evaluation

All roosts reported here were diurnal roosts of *M. sodalis*; roosts were defined as the entire tree occupied by *M. sodalis*. No artificial structures (e.g., barns, human dwellings, bridges) were used as roosts by *M. sodalis* in this study. Roost sites were defined as specific areas ($\leq$1-m segment) of a roost tree where one or more *M. sodalis* roosted. Each roost was marked with a uniquely numbered brass tag affixed to its base and ranked according to its potential to provide roost sites beneath its bark. Ranking was based upon a visual assessment of the amount of loose and peeling bark on a tree's trunk and limbs: high = $\geq$25% coverage; moderate = $\geq$10% but <25%; low = <10%; none = devoid of loose and peeling bark. Data recorded for each roost included location in Universal Transverse Mercator (UTM) coordinates, date discovered, tree species and condition (dead or alive), relative elevation (upland or floodplain), diameter of tree at breast height (cm dbh), tree height (m), height of roost site above ground (m), type of roost site (bark or cavity), thickness of bark (cm), and total number of bats present. The sex, age, reproductive condition, and numerical identity of radio-tagged bat(s) within the roost were recorded. ARC/INFO Geographic Information System (GIS) software was used to record the nearest distance ($\pm$1 m) to paved roads, unpaved roads, perennial streams, intermittent streams, and the original point of capture of the radio-tagged bat(s) from that roost tree for which data were recorded. Where foraging range data for radio-tagged bats were collected, the relationship of their roost to the geometric center of their foraging range was measured.

Habitat types surrounding each roost were determined by ground-truthing, interpretations of aerial photography, and ARC/INFO GIS analysis for the Fishhook Creek study area. Woody vegetation was measured within 0.10 ha circular plots surrounding 32 of the 39 roosts at Fishhook Creek. All woody stems $\geq$10 cm dbh were recorded as living or dead and by species and size (cm dbh). Understory trees, shrubs and ground cover (herbaceous and woody species) were also recorded.

Percent forest canopy closure readings were taken at each roost using a hand-held densitometer at the base of the roost and at 5-m intervals from the base in each of the four cardinal directions (eight readings total). Roosts were revisited every spring or summer after their discovery (beginning with the first roost found in 1986) through 1989 to assess their continuing suitability for roost sites and to determine their rate of attrition.

Censusing Roosts

Bats emerging from roosts were counted simultaneously by two or more experienced observers. Censuses were occasionally aided by a night vision scope (15x). To keep disturbance to a minimum, no artificial lighting was used; silhouettes of bats emerging from their roosts against a sunset sky were easily recognized. Bats almost always emerged individually from the same place in the roost site. We felt that exit counts at dusk were reliable indicators of total numbers of bats in the roost since emergence times for radio-tagged *M. sodalis* and their almost immediate movement to foraging area(s) occurred before it became too dark to see. Reliability continued until mid- to late-July when juveniles were becoming volant. Bats that emerged from colonial roost sites after mid- to late-July circled the roost tree and often re-entered the roost site; this type of behavior made censuses of larger populations more difficult and less reliable.

Even if we had been able to reach every roost site safely, we routinely avoided removing or otherwise disturbing roosting bats. The removal of *M. sodalis* from diurnal roosts was a traumatic disturbance, which affected their subsequent roosting behavior. Furthermore, pulling on a loose piece of bark frequently destroyed the roost site. Individuals were removed from 7 of the 48 roosts located during two years of study.

Roost Microclimate

Thermodynamic characteristics of selected roost sites within the Fishhook Creek study area could be measured for up to seven consecutive days with battery-powered millivolt strip chart recorders using type "T" (copper-constantine) thermocouple probe assemblies (Omega Engineering Inc., Stamford, Connecticut). A linearized thermocouple to analog amplifier provided a precise 1 mV/degree C conversion accurate to $\pm$ 0.4 degrees C. Temperature probes were installed beneath the bark. Supplemental external environmental data were recorded, including daily maximum/minimum temperature (C), precipitation (mm), and cloud cover (Orr Agricultural Research Station, U.S. Department of Agriculture, located <7 km east of the study area).

DESCRIPTION OF STUDY AREA

Attempts to capture *Myotis sodalis* in riparian habitats and find their roosts were conducted throughout Illinois from 1985 through 1989. Riparian habitats are considered the most important habitat available to summer populations of *M. sodalis*

(U.S. Fish and Wildlife Service 1983). At present, these habitats exist throughout Illinois primarily as noncontiguous, narrow strips along streams and rivers. Although a larger (>38 %) and more contiguous area of Illinois was forested during pre-settlement times, much of the present-day expanse of agriculture in Illinois was native prairie (>62 %; Iverson *et al.* 1989). Upland slopes are usually covered by highly fragmented forests that are often grazed by livestock. In less agriculturalized regions of the state, these forested uplands are often contiguous to the forested riparian corridors. The largest, most contiguous forested uplands and floodplains in Illinois remain across southern portions of the state, in the counties between and bordering the Mississippi and Illinois rivers, and in the northwestern corner of the state. Forested areas in northeastern Illinois occur primarily in conjunction with heavily urbanized and industrial settings. Heterogeneous mixes of forests and agriculturally cleared lands (other than row crops) are found most frequently in areas of greatest topographic relief along the Mississippi, Ohio, and lower Illinois rivers. Despite its predominantly agricultural character, Illinois provides a surprisingly diverse habitat for summer populations of *M. sodalis*.

Intensive radio-tracking efforts focused on the Fishhook Creek watershed in north-central Pike and southeastern Adams counties (Figure 1). Fishhook Creek, a secondary tributary to the Illinois River (via McKee Creek) in west-central Illinois, flows in a narrow (7-16 m), shallow (2-4 m) channel that gently winds through a sparsely populated rural area. The stream bottom was primarily clean sand and gravel but deep siltation and drift dams were common. Riffles were shallow, infrequent (<1/100 m) and connected by shallow pools. Although Fishhook Creek is classified as a perennial stream, water usually remained in its channel only as isolated, somewhat stagnant pools by early to mid-August. Flash flooding was common and erosion of nonforested stream banks was evident; however, nonforested stream banks were uncommon and short (<100 m) in length.

The Fishhook Creek study area was characterized by a heterogeneous mix of forested lands interspersed with cropland, pasture, old field, and a variety of other open (nonforested) land (Figure 1). Habitat types within the 3,672 ha study area and their percent total cover were cropland (43.28%), hayland/pasture (18.24%), old field (3.68%), other agricultural land (1.97%; e.g., residential yards, barnyards, feedlots), closed canopy upland forests (24.41%), closed canopy floodplain forests (1.67%), intermediate canopy upland forests (5.18%), intermediate canopy floodplain forests (0.42%), open canopy upland forests (0.90%), open canopy floodplain forests (0.13%), and farm ponds (0.13%). Most upland slopes were second and/or third growth and were frequently heavily grazed. Floodplain forests were narrow, irregularly shaped strips bordering Fishhook Creek. They seldom were large enough to warrant grazing unless they were contiguous with grazed upland forests.

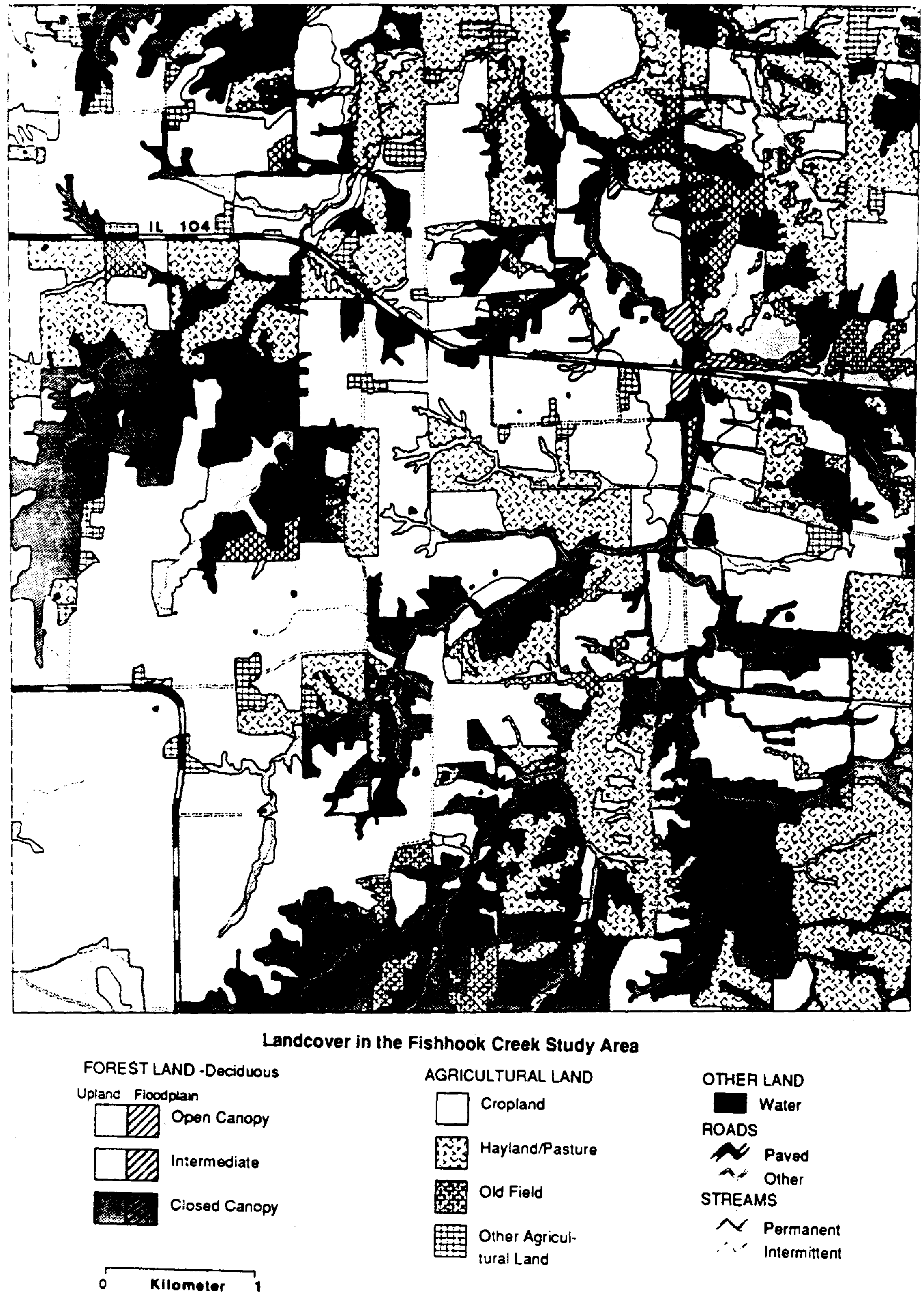

Figure 1. Habitat cover types, roads, and streams in the Fishhook Creek study area, Pike and Adams counties, Illinois.

Dominant canopy trees (≥10 cm dbh) common in forested upland slopes, terraces, and ridgetops in order of decreasing abundance were *Quercus alba* (white oak), *Carya ovata*, *Ulmus rubra* (slippery elm), *Fraxinus americanus* (white ash), *Robinia pseudoacacia* (black locust), *Quercus imbricaria* (shingle oak), *Quercus rubra* (northern red oak), and *Quercus bicolor* (swamp white oak). Within the upland plots, common shrubs and understory trees, other than saplings (<10 cm dbh) of dominant canopy species, included *Amelanchier arborea* (shadbush), *Cornus drummondii* (rough dogwood), *Cornus florida* (flowering dogwood), *Corylus americana* (hazelnut), *Crataegus* sp. (hawthorn), *Rhus aromatica* (fragrant sumac), and *Viburnum prunifolium* (nannyberry). Grasses, herbaceous ground cover, or other woody species commonly encountered in the uplands included *Agrostis alba* (redtop grass), *Coreopsis palmata* (stiff coreopsis), *Festuca pratensis* (tall fescue), *Menispermum canadense* (moonseed), *Osmorhiza* sp. (sweet cicely), *Parthenocissus quinquefolis* (Virginia creeper), *Ribes* sp. (gooseberry), *Symphoricarpos orbiculatus* (coralberry), *Viola* sp. (violet). In addition to the species mentioned above, some species found commonly in upland forests were also found in floodplain forests: *Ambrosia trifida* (giant ragweed), *Carex* sp. (sedge), *Elymus virginicus* (virginia wild rye), *Galium aparine* (bedstraw), *Podophyllum peltatum* (mayapple), *Rubus* sp. (brambles/blackberry/raspberry), *Rosa multiflora* (multiflora rose), *Solidago* sp. (goldenrod), *Toxicodendron radicans* (poison ivy), and *Vitus* sp. (wild grape).

Dominant canopy trees (≥10 cm dbh) common in floodplain forests, listed in order of decreasing abundance, included *Acer saccharrinum* (silver maple), *Populus deltoides* (cottonwood), *Ulmus rubra*, *Acer negundo* (box elder), *Juglans nigra* (black walnut), and *Plantanus occidentalis* (sycamore). Shrubs and understory trees, other than saplings (<10 cm dbh) of dominant canopy species listed above, common in floodplain forests included *Aesculus glabra* (Ohio buckeye), *Cornus drummondii*, *Corylus americana*, *Crataegus* sp., *Morus alba* (white mulberry), and *V. prunifolium.* Ground cover (herbaceous or woody) commonly encountered in the floodplain, but not normally shared with the uplands, included *Helianthus tuberosa* (jerusalem artichoke), *Impatiens* sp. (jewelweed), *Laportea canadensis* (stinging nettles), and *Sanicula canadensis* (canada black snakeroot). Whether in the floodplain or in the upland, such species as *A. trifida, E. virginicus, G. aparine, H. tuberosa, R. multiflora, and S. canadensis* occurred only in more open forest canopies or along forest edges.

Dead trees that provided potential roost structures (loose and peeling bark) for bats within the Fishhook Creek study area were recorded within 32 tenth-hectare plots. Species common in upland forests, listed in order of decreasing abundance, were *U. rubra*, *Q. rubra*, *Q. alba*, *Quercus sp.*, *Q. stellata*, *Carya tomentosa* (mockernut hickory), *Q. imbricaria*, and *C. ovata.* In floodplain forests, *A. saccharinum*, *P. deltoides*, *U. rubra*, *A. negundo*, *Betula nigra* (river birch), and *J. nigra* were the only species of standing dead trees encountered.

Because of its rural nature, varied topography, and the diversity of foraging and roosting habitats available to bats, the Fishhook Creek area was well suited for detailed studies of *M. sodalis*. Additionally, repeated mist netting had previously determined the area to be suitable maternity habitat for Indiana bats. Land owners throughout the study area were extremely cooperative and allowed unlimited access to their property.

RESULTS

General Perspective

From May 1986 through September 1989 we found more than 326 *Myotis sodalis* roosting in 48 roost trees in eight Illinois counties (Figure 2). One roost contained 95 bats during June 1988 and 50 bats during September 1989. Two separate roosts housed 18 bats each. Fifty-six bats were found roosting individually, nine roosts contained two to six bats, and six roosts contained eight to fifteen bats. Thirty-five roosts were documented within the Fishhook Creek study area, Pike and Adams counties (Figure 3). Four roosts (918, 919, 920, 937) occurred outside the limits of the study area and are not shown in Figure 3.

Twelve tree species were used as roosts (Table 1); listed in order of decreasing abundance they were *Ulmus rubra* (n = 12); *Quercus rubra* (n = 9); *Carya ovata* (n = 6); *Acer saccharinum* (n = 5); *Populus deltoides* (n = 4); *Quercus stellata* (post oak, n = 4); *Carya cordiformis* (n = 2); *Sassafras albidum* (sassafras, n = 2); *Acer saccharum* (sugar maple, n = 1); *Quercus alba* (n = 1); *Quercus imbricaria* (n = 1); and *Ulmus americana* (n = 1).

The first *M. sodalis* roost tree (901; Appendix, Figure A-1) was discovered on 14 May 1986 while haphazardly searching for colonies of nonradio-tagged bats. This roost was found after examining >2,000 potential roost trees from 1980 through 1989. Radio-transmitter attachment to 31 *M. sodalis* (17 adult females, 7 adult males, 5 juvenile females, 2 juvenile males) from September 1986 through July 1989 allowed us to locate an additional 47 roost trees. Twenty-two of the 48 roost trees were used by pregnant and/or lactating females, three by post-lactating adult females, nine by volant juveniles, and 19 by adult males.

Myotis sodalis typically roosted beneath the exfoliating bark of dead trees (41 of 48 roosts). Other roost sites were beneath the bark of living trees (n = 4) and within the cavities of dead trees (n = 3). Thirty-seven roost trees were found in upland situations (elevations >1 m above 100-year floodplain of perennial streams) and eleven trees within floodplains. Within forested habitats, 32 roost trees occurred within closed (80%-100%) canopies and 12 within intermediate (30%-80%) canopies. Of 44 roosts in forested habitats, 26 were located in areas grazed by livestock. A single roost tree was found in each of the following habitat types; a palustrine wetland with

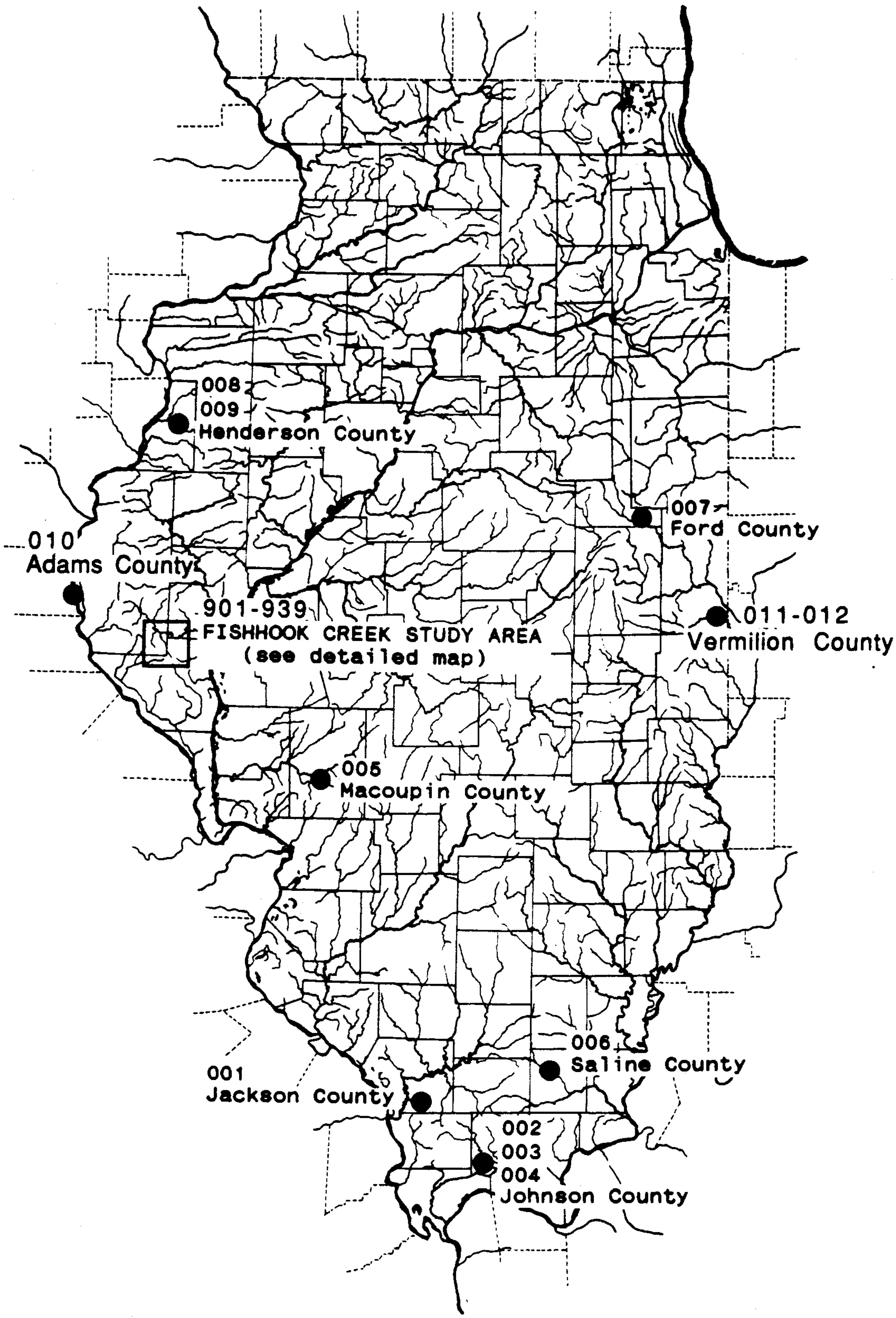

Figure 2. Location of 51 *Myotis sodalis* roost trees found in Illinois from May 1986 through August 1990. Numbers correspond to roost tree numbers used in this report; however, roost 010 in Adams County and roosts 011 and 012 in Vermilion County are not discussed.

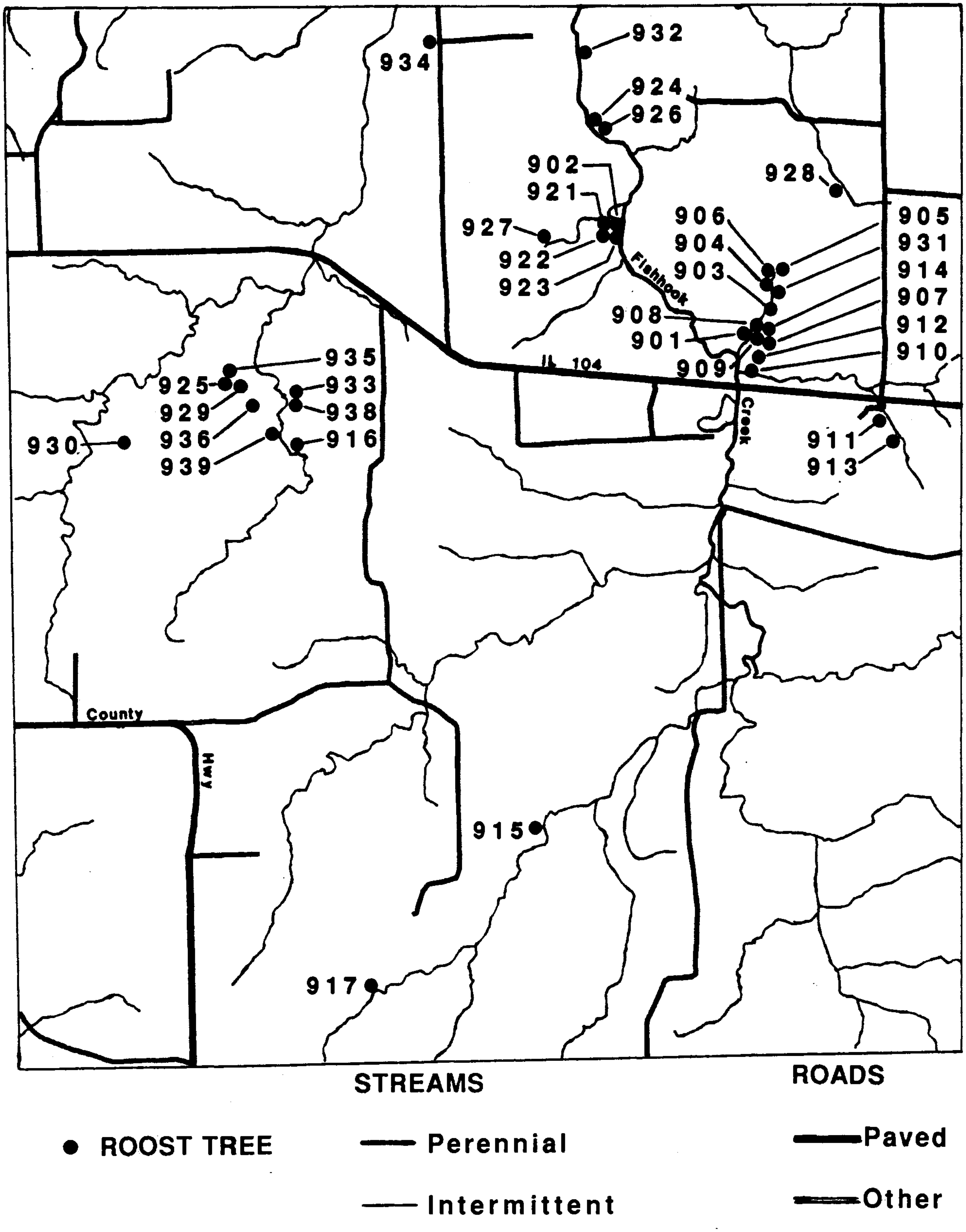

Figure 3. Location of 35 of the 39 *Myotis sodalis* roost trees in relation to roads and streams in the Fishhook Creek study area, Pike and Adams counties, Illinois. Numbers correspond to roost tree numbers used in this report.

Table 1. Characteristics of 48 roost trees used by *Myotis sodalis* in eight Illinois counties from 14 May 1986 through 11 July 1989.

ROOST NO.	COUNTY	DATE LOCATED	DBH (cm)	CONDITION	RELATIVE ELEVATION	HABITAT CLASS	BAT ID TRX NO.	FEMALE PG	FEMALE L	FEMALE PL	FEMALE JUV	MALE JUV	MALE ADULT	TOTAL NO. BATS	ROOST SITE STRUCTURE	BARK THICKNESS (cm)	ROOST SITE HEIGHT (m)
Acer saccharinum																	
001	Jackson	05/20/87	31	dead	floodp	Clr	F122b	1						>1	bark		> 4.0
922	Adams	05/01/87	40	alive	floodp	CC,NGz	F263a	1						1	bark	0.7	13.0
923	Adams	05/04/87	24	dead	floodp	CC,NGz	F263a	1						1	cavity	0.6	6.0
924	Adams	05/17/88	35	dead	floodp	CC,NGz	F083		1					1	cavity	0.9	3.5
924		06/16/88					F484		1					1	cavity		> 3.0
926	Adams	05/18/88	50	alive	floodp	CC,NGz	F083		1					1	bark	0.5	> 4.0
Acer saccharum																	
002	Johnson	07/14/87	33	dead	upland	CC,Gz	M323						1	1	bark		> 4.0
Carya cordiformis																	
911	Pike	06/23/87	24	dead	upland	CC,NGz	F444		1					1	bark	1.0	> 5.0
934	Adams	07/25/88	24	dead	upland	SwF	M182						1	1	bark	1.3	> 4.0
934		07/27/88					M182						1	1	bark		> 4.0
934		07/28/88					M182						1	1	bark		> 4.0
Carya ovata																	
009	Henderson	07/12/89	39	dead	upland	IC,NGz	F138		1					1	bark		> 8.0
919	Adams	06/19/87	39	alive	upland	IC,Gz	M181						1	1	bark	0.8	> 4.0
920	Adams	06/23/87	58	alive	upland	IC,Gz	M181						1	4	bark	0.9	1.3
920		05/25/88					na	1					4	5	bark		1.3
925	Adams	05/17/88	42	dead	upland	CC,Gz	F363	1						58	bark	2.8	10.0
925		05/18/88					F363	1						?	bark		10.0
925		05/19/88					F363	1						?	bark		10.0
925		05/20/88					F363	1						?	bark		10.0
925		06/13/88					na		1					95	bark		10.0
925		06/14/88					F282,F163		2					?	bark		10.0
925		06/15/88					F163		1					?	bark		10.0
925		06/16/88					F163		1					?	bark		10.0
925		06/20/88					F163		1					?	bark		10.0
925		06/21/88					F163		1					?	bark		10.0
925		06/22/88					F163		1					?	bark		10.0
925		09/20/89					na			8		1	4	50	bark		5.5
931	Pike	06/15/88	32	dead	upland	CC,Gz	F484		1					1	bark	1.0	> 4.0
935	Adams	07/27/88	27	dead	upland	CC,Gz	M424,M721, F501			6	1	3		14	bark	1.4	> 4.0
Populus deltoides																	
902	Adams	09/05/86	45	dead	floodp	CC,NGz	F122a				1			10	bark	1.8	>12.0
917	Adams	07/28/87	41	dead	upland	CC,NGz	F342			1				1	bark	2.1	> 8.0
917		07/29/87					F342			1				1	bark		> 8.0
917		07/30/87					F342			1				1	bark		> 8.0
921	Adams	05/05/87	41	dead	floodp	CC,NGz	F263a	1						3	bark	1.7	> 8.0
921		05/06/87					F263a	1						1	bark		> 8.0
921		05/07/87					F263a	1						1	bark		> 8.0
921		05/08/87					F263a	1						1	bark		> 8.0
932	Adams	06/20/88	46	dead	floodp	CC,NGz	F484		1					1	bark	2.0	> 4.0
932		06/21/88					F484		1					1	bark		> 4.0

Table 1. (continued)

ROOST NO.	COUNTY	DATE LOCATED	DBH (cm)	CONDITION	RELATIVE ELEVATION	HABITAT CLASS	BAT ID TRX NO.	FEMALE PG	FEMALE L	FEMALE PL	FEMALE JUV	MALE JUV	MALE ADULT	TOTAL NO. BATS	ROOST SITE STRUCTURE	BARK THICKNESS (cm)	ROOST SITE HEIGHT (m)
Quercus alba																	
939	Adams	08/04/88	18	dead	upland	CC,Gz	F501				1			1	bark	0.7	8.1
Quercus imbricaria																	
908	Pike	06/19/87	28	dead	upland	IC,Gz	M462						1	1	bark	0.9	> 4.0
Quercus rubra																	
901	Pike	05/14/86	41	dead	upland	IC,Gz	na	3						18	bark	1.4	5.5
903	Pike	05/05/87	61	dead	upland	IC,Gz	M383	1					1	6	bar	1.4	2.0
903		05/25/88					F083		1					1	bark		> 4.0
913	Pike	06/25/87	22	dead	upland	CC,NGz	F444		1					1	bark	1.2	> 4.0
915	Adams	07/21/87	56	dead	upland	CC,NGz	F342			1				1	bark	1.6	>10.0
915		07/22/87					F342			1				1	bark		>10.0
915		07/23/87					F342			1				1	bark		>10.0
927	Adams	05/19/88	83	dead	upland	CC,NGz	F083		1					1	bark	1.8	> 4.0
928	Pike	05/20/88	64	dead	upland	IC,Gz	F083		1					1	bark	0.8	> 4.0
928		05/23/88					F083		1					1	bark		> 4.0
933	Adams	06/21/88	31	dead	upland	CC,Gz	F282		1					1	bark	1.0	> 6.0
933		07/28/88					F501				1			1	bark		> 6.0
933		08/04/88					M721			3	2	4		9	bark		6.0
936	Adams	07/28/88	45	dead	upland	CC,Gz	M721					1		1	bark	2.1	> 4.0
936		07/29/88					M721					1		1	bark		> 4.0
938	Adams	07/29/88	27	dead	upland	CC,Gz	F501				1			1	bark	1.2	> 5.5
938		08/02/88					F501,M721				1	1		>2	bark		> 5.5
938		08/03/88					F501,M721				1	1		11	bark		5.5
Quercus stellata																	
005	Macoupin	08/06/87	25	dead	upland	Pas,Gz	F541			1				>1	bark		1.5
904	Pike	05/04/87	36	dead	upland	CC,Gz	M383						1	1	bark	1.8	> 4.0
905	Pike	05/01/87	36	dead	upland	CC,Gz	M383						1	1	bark	1.8	4.5
905		05/06/87					M383						1	1	bark		4.5
905		05/07/87					M383						1	1	bark		4.5
905		09/19/89					na			1				8	bark		2.8
929	Adams	05/26/88	39	dead	upland	CC,Gz	na	?						2	bark	1.3	> 8.5
Sassafras albidum																	
004	Johnson	07/23/87	29	dead	upland	CC,Gz	M323						1	1	bark		> 5.0
918	Adams	06/18/87	8	dead	upland	CC,Gz	M181						1	4	cavity	1.3	4.0

Table 1. (concluded)

ROOST NO.	COUNTY	DATE LOCATED	DBH (cm)	CONDITION	RELATIVE ELEVATION	HABITAT CLASS	BAT ID TRX NO.	FEMALE PG	FEMALE L	FEMALE PL	FEMALE JUV	MALE JUV	MALE ADULT	TOTAL NO. BATS	ROOST SITE STRUCTURE	BARK THICKNESS (cm)	ROOST SITE HEIGHT (m)
Ulmus americana																	
006	Saline	05/10/88	33	dead	floodp	Wetland	F263b	1						1	bark		> 8.0
Ulmus rubra																	
003	Johnson	07/15/87	28	dead	upland	CC,Gz	M323						1	1	bark		> 6.0
007	Ford	07/15/88	78	dead	floodp	CC,NGz	F524		1					5	bark		> 4.0
007		07/16/88					F524		1					> 1	bark		> 4.0
008	Henderson	07/11/89	51	dead	upland	CC,NGz	F138		1					18	bark		>10.0
906	Pike	05/08/87	33	dead	upland	CC,Gz	M383						1	1	bark	1.0	> 4.0
907	Pike	06/18/87	14	dead	upland	IC,Gz	M462						1	1	bark	0.6	5.0
909	Pike	06/22/87	44	dead	upland	IC,Gz	M462						1	1	bark	1.0	2.5
910	Pike	06/23/87	22	dead	floodp	IC,Gz	M462						1	1	bark	0.7	> 4.0
910		06/25/87					M462						1	1	bark	0.7	> 4.0
912	Pike	06/24/87	24	dead	upland	IC,Gz	M462						1	1	bark	0.5	2.3
914	Pike	06/26/87	18	dead	upland	IC,Gz	M462						1	1	bark	0.8	2.4
916	Adams	07/22/87	38	dead	upland	CC,Gz	M223					1		1	bark	0.8	> 8.0
930	Adams	07/26/88	18	dead	upland	CC,NGz	M244					1		1	bark	1.0	> 4.0
930		07/27/88					M244					1		1	bark		> 4.0
930		07/28/88					M244					1		1	bark		> 4.0
930		07/29/88					M244					1		1	bark		> 4.0
930		08/02/88					M244					1		1	bark		> 4.0
930		08/03/88					M244					1		1	bark		> 4.0
937	Adams	07/28/88	40	dead	upland	CC,NGZ	M424					1		1	bark	1.2	> 4.0

emergent vegetation (inundated through mine subsidence) that contained hundreds of other dead trees, a heavily grazed ridgetop pasture containing a few scattered dead trees (some, including the roost tree, partially burned and blackened), a partially wooded swine feedlot, and a clearcut encircling a segment of an intermittent stream where selected dead trees were retained for wildlife. Roost trees were not found in forests with open canopies (10%-30%) or in habitats classified as old field (≤10% canopy closure if trees were present), residential, and agriculturally cleared lands other than pastures with trees.

Specific Roost Perspective

The above data indicate that *Myotis sodalis* is somewhat adaptable in its selection of suitable roost trees, however, its requirements for roost sites are more specific. Only certain tree species possess inherent morphological characteristics that fall within the range of these roost requirements. The following information, beginning with tree species chosen most frequently as roosts, is provided in an effort to clarify preferences that *M. sodalis* may have in roost selection. Roost tree numbers that begin with nine were within the Fishhook Creek study area.

Ulmus rubra (slippery elm)

Ulmus rubra (n = 12) was used more frequently a roost site by *M. sodalis* than any other species of tree. All *U. rubra* roost trees were dead, with roost sites occurring beneath the bark at heights of more than 2.3 meters above the ground. Lactating adult females F138 and F524 were tracked to *U. rubra* roosts 008 and 007, respectively. Eighteen bats (presumed to be adult females) were observed emerging from roost 008 on 11 July 1989, and five bats (sex undetermined) flew from roost 007 at dusk on 15 July 1988. Thus *U. rubra* appeared to be a potentially significant species used by reproductively active females. The remaining ten *U. rubra*, however, were used either by solitary, nomadic adult males (n = 7) or by juvenile males (n = 3).

Within a period of eight days, one adult male (M462) used five of 12 *U. rubra* roosts (907, 909, 910, 912, 914). These roosts occurred in a <6-ha upland forested area encircling an intermittent drainage. *Ulmus rubra* roost 906 (Appendix, Figure A-5) was one of four (903, 904, 905, 906) roosts used by adult male M383 during 1987; all roosts were within 275 m of each other.

Quercus rubra (northern red oak)

Dead *Quercus rubra* (n = 9) was an important species providing suitable roost structures for reproductively active (pregnant and lactating) *M. sodalis*. All nine *Q. rubra* were used either by pregnant and lactating adult female or by volant juveniles.

The first maternity colony of *M. sodalis* (n = 18) was discovered in *Q. rubra* 901 (Appendix, Figure A-1) on 14 May 1986. The first three bats (nonradio-tagged, pregnant adult females) to emerge from this roost were captured in mist nets. Roost 933 was used by a lactating adult female (F282) on 21 June 1988, by a juvenile female (F501) on 28 July 1988, and by a juvenile male (M721) and eight other bats on 4 August 1988. Another *Q. rubra* (938), less than 9 m from roost 933, was simultaneously occupied by juveniles F501 and M721 and nine other bats on 2-3 August 1988. Roost 903 (Appendix, Figure A-3) was used by *M. sodalis* for two consecutive years; a radio-tagged male (M383), a pregnant female, and four bats that escaped handling were found there on 5 May 1987; a radio-tagged lactating female (F083) was tracked there on 25 May 1988. Three of the five roosts used by F083 were *Q. rubra* (903, 927, and 928). Juvenile male M721, captured from *Carya ovata* (shagbark hickory) roost 935 on 27 July 1988, selected three *Q. rubra* roosts during 1988. He used roost 936 from 28-29 July, roost 938 with a juvenile female (F501) on 2 August, and roost 933 on 4 August where he was recaptured with three post-lactating adult females, two juvenile females, and three juvenile males. A post-lactating adult female (F342) used *Q. rubra* roost 915 (Appendix, Figure A-6) for three consecutive days until human disturbance (roost examination) caused him to abandon it.

Quercus stellata (post oak)

All *Q. stellata* roosts were dead trees. A post-lactating female (F541) was radio-tracked to a partially burned *Q. stellata* (005) in an upland pasture near the edge of a forested slope on 6 August 1987. This roost contained an unknown number of other bats (presumably *M. sodalis*). *Quercus stellata* roosts 904 and 905 (Appendix, Figure A-4) were used by a solitary nomadic male (M383) during 1987. Roost 905 was also occupied on 19 September 1989 by a post-lactating adult female and seven other bats that escaped handling. Roost 929 (Appendix, Figure A-9) apparently served as an alternate roost during late May and early June 1988 for the *M. sodalis* maternity colony using *Carya ovata* 925, eight meters away.

Carya ovata (shagbark hickory)

The most important roost tree in terms of numbers of *M. sodalis* was *C. ovata* roost 925 (Appendix, Figure A-9). This roost was discovered by radio-tracking a pregnant adult female (F363) from her original capture site over Fishhook Creek, more than 2.5 km east of the roost. We observed at least 58 individuals (including F363) emerging from beneath a single piece of exfoliating bark on this roost during an exit count conducted 17 May 1988. Bats were not present at roost 925 on 23 May, but 95 individuals had returned to the original roost site by 13 June. Two lactating adult females were captured in mist nets as they emerged from roost 925 on 14 June 1988 and radio-tagged (F282 and F163). Why the bats abandoned this roost after 24 July is unclear; however, a combination of natural dispersal (young becoming volant and self-sufficient) and disturbances (our activity at the roost combined with frequent rubbing of the tree by cattle) was suspected. Roost 925 was examined on 20 September 1989 and found to contain $\geq$50 *M. sodalis*. Eight nonreproductive adult females, one nonreproductive juvenile male, one nonreproductive adult male, and three partially scrotal adult males were examined. These bats occupied a roost site on the main trunk 2 m lower than the site used in 1988 (Appendix A, Figure A-9).

Carya ovata roosts 009 and 931 were used for one day by F484 and F138, respectively; both bats were lactating adults. Six post-lactating adult females, three juvenile males, and one juvenile female were removed from beneath the bark of roost 935 on 27 July 1988 after a radio-tagged juvenile male (M424) was located at this site. This tree was the only roost tree that leaned significantly (angle $\leq$50 degrees to the ground); a nearby tree had prevented it from falling completely. Roost 935 was located 100 m NNW from maternity roost 925, suggesting that at least some of these individuals were from 925. On 19 June 1987, a radio-tagged adult male (M181) was tracked to a living *C. ovata* (919). On 23 June 1987, M181 and three other adult males were captured in roost 920 (Appendix, Figure A-7), from beneath a small piece of bark 1.3 meters above the ground in a living *C. ovata* less than 50 m uphill from roost 919. On 25 May 1989, roost 920 was revisited and four adult males and one pregnant female were captured.

Carya cordiformis (bitternut hickory)

A dead *C. cordiformis* (911) was one of two roosts used by a solitary lactating adult female *M. sodalis* (F444) from 23-25 June 1987. A nomadic adult male (M182) roosted in a *C. cordiformis* (934) on 25 July 1988 and returned on 27-28 July.

Populus deltoides (cottonwood)

Dead *P. deltoides* (n = 4) were used as roosts solely by pregnant, lactating, or post-lactating adult and juvenile female *M. sodalis*. *Populus deltoides* roost 902 (Appendix, Figure A-2), found on 5 September 1986, was the second roost tree discovered in Illinois and the first identified by radio-tracking. A radio-tagged juvenile female (F122a) and nine other bats were observed at dusk emerging from beneath loosely hanging bark on this roost tree. This juvenile used the roost site until at least 11 September 1986, and returned to the Fishhook Creek study area in 1988 as a lactating adult female; she was hereafter known as F083. During 1988, F083 used five different roosts (903, 924, 926, 927, and 928), all within 1.4 km of roost 902.

From 5 May 1987 through 8 May 1987, a radio-tagged pregnant adult female (F263) roosted with at least three other bats in *P. deltoides* roost 921. The transmitter from F263 was recovered from the ground beneath *A. saccharinum* roost 922 (31 m west of roost 921) on 14 May. The bark was completely stripped from roost 921 on June 2 1987 during a 40-min. period of hail (2.54 cm), heavy rain (0.73 cm), and high winds. No evidence of mortality was found beneath the destroyed roost site following this natural catastrophe. Roost 921, used by pregnant adult F263 during 1987, and roost 902, used by juvenile female F122a during 1986, occurred 21 m apart within a <1.2 ha floodplain forest bordering Fishhook Creek. *Populus deltoides* roost 917 was used by post-lactating adult female F342 from 28-30 July 1987, and *P.*

deltoides roost 932 was used from 20-21 June 1988 by lactating adult female F484.

Acer saccharinum (silver maple)

Three dead and two living *Acer saccharinum* were used as roosts by adult female *M. sodalis*. Before pregnant adult F263 selected *P. deltoides* roost 921, she roosted either in a small cavity or beneath the loose bark of a dead limb attached to a living *A. saccharinum* (roost 922) on 1 May 1987. This female used dead *A. saccharinum* roost 923 on 4 May. Lactating adult female F484 roosted in dead *A. saccharinum* roost 924 (Appendix, Figure A-8) on 16 June 1987 and another lactating adult female (F083) roosted in a living *A. saccharinum* (926) on 18 May 1988. These two roosts were only 13 m apart. On 20 May 1987, pregnant female F122b was tracked to dead *A. saccharinum* roost 001. This roost (Figure 2) was one of many dead trees retained through the application of wildlife management guidelines in an area of the Shawnee National Forest in Jackson County that had been clearcut in December 1983 (USDA, Forest Service, pers. comm.). Other bats were heard from beneath the bark of this maternity roost and fresh guano was found scattered on the surrounding vegetation.

Other Species

A dead *Quercus imbricaria* (908) was one of six roosts used by a nomadic adult male (M462) during 1987. Fifteen bats, including a radio-tagged juvenile female (F501), flew from a dead *Q. alba* (939) on 4 August 1988, after we disturbed the tree. A dead *A. saccharum* (002) was used as a roost on 14 July 1987 by a solitary adult male (M323), who also roosted in a dead *S. albidum* (004) on 23 July and a dead *U. rubra* (003) on 15 July. The latter three trees occurred in a heavily grazed upland forest more than 2.7 km from the original capture site of this bat over the Cache River, Johnson County. An adult male (M181) and three other bats were flushed from a very small cavity in the trunk of an 8 cm dbh *Sassafras albidum* (918) on 18 June 1987. A pregnant female (F263) was tracked to an *U. americana* (006) on 10 May 1988.

Microclimate Analysis and Thermodynamic Properties of Selected Roost Sites

The growth and development rates of bat embryos are affected by roost site temperatures and the food resources available to the pregnant adults (Racey 1973: Tuttle 1975). For example, low temperatures may result in delayed fetal development (Racey and Swift 1981; Racey 1982), and high roost site temperatures, not exceeding tolerance limits, may result in accelerated fetal development (Racey 1973). Studier and O'Farrell (1972) demonstrated that adult female *M. sodalis* with nearly full-developed fetuses and neonates thermoregulate poorly. Studies of *M. sodalis* in winter revealed that their body temperature varied proportionately to ambient air temperatures within the range of 5-35 C. Within this range, body temperature remained 1-1.5 C above ambient temperatures (Henshaw 1970; Thomson 1982). When male bats from bachelor colonies in mines and caves were subjected by researchers to ambient temperatures above 35 C, their correspondingly high body temperatures proved stressful, and even fatal, during the period of expected spring (March to April) arousal (Henshaw and Folk 1966). Their study of the physiological characteristics of *M. sodalis* was not conducted in the microclimates of roosts beneath the bark and, therefore, may not be wholly applicable to summer roosts.

The rate at which partially detached bark and the air space created beneath the bark are heated by solar radiation is affected by its amount of exposure to solar radiation, the angle of incidence (solar aspect), the propensity of bark fibers to absorb radiation (i.e., color, texture, density), and the moisture content of the bark. Conversely, the rate at which heat is dissipated depends upon the insulatory qualities and moisture content of the bark. All of these qualities, in turn, are influenced by the circulation of air beneath the bark. These thermodynamic characteristics of a tree (alive or dead) determine its suitability as a roost site.

Humphrey *et al.* (1977) investigated the response of a *M. sodalis* maternity roost site to weather conditions and the affect of changes in roost site temperature on roosting behavior. They determined that a dry dead *C. cordiformis* used as a maternity roost trapped heat from solar radiation more effectively than a living *C. ovata*; however, the living *C. ovata* was more efficient at retaining previously stored heat during autumn. Because the living tree was generally cooler during the day, it provided an escape from the potentially lethal maximum temperatures that occurred beneath the bark of the dead tree when exposed to intense solar radiation. For comparative purposes, the affect on *M. sodalis* roost sites of varying weather conditions are presented in this report in a format similar to that used by Humphrey *et al.* (1977).

Roost 901: *Quercus rubra*

The bark covering the roost site of this dead tree was interrupted only by a small horizontal crack from which the colony emerged (Appendix, Figure A-1). Very little air exchange occurred through this narrow opening. Although air spaces beneath the bark allowed the bats to move, these spaces were less numerous than spaces in other roost sites (e.g., 921, 925). The tree received direct solar radiation on its southern side.

Temperatures within the 901 maternity roost site ranged from a maximum of 30 C on 2 May (mean maximum = 23 C) to a minimum of 7 C on 5-6 May (mean minimum = 10 C; Figure 4). Temperatures within the roost site were obviously affected by two days of overcast skies and one day of rain (8.4 mm). Although the roost site was located on the shaded NNW side of the tree, rates of increase in roost site temperatures were often >2 C/hr during early mornings with clear weather (Figure 5). Temperatures within the roost most often reached maximum levels by 1500 hrs; minimum levels usually occurred just prior to sunrise.

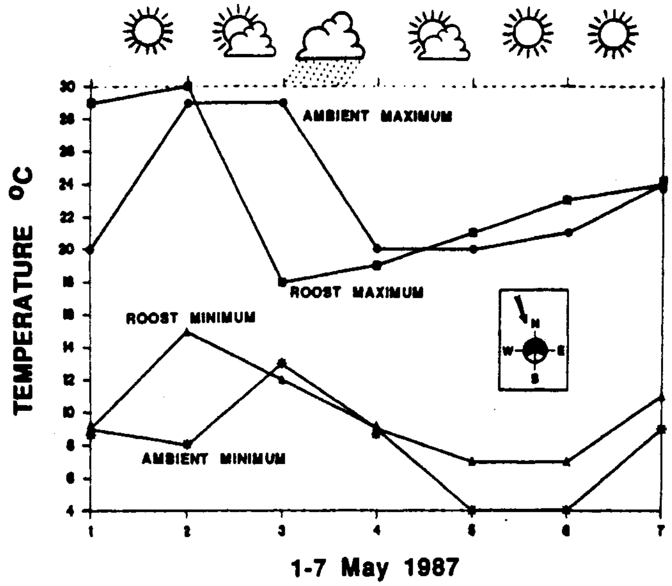

Figure 4. Daily maximum and minimum ambient air and roost site (beneath bark) temperatures for *Myotis sodalis* maternity roost 901 (*Quercus rubra*) from 1-7 May 1987 in relation to selected environmental events. Inset indicates location of roost site (arrow) and shading from the forest canopy (shaded portion of circle).

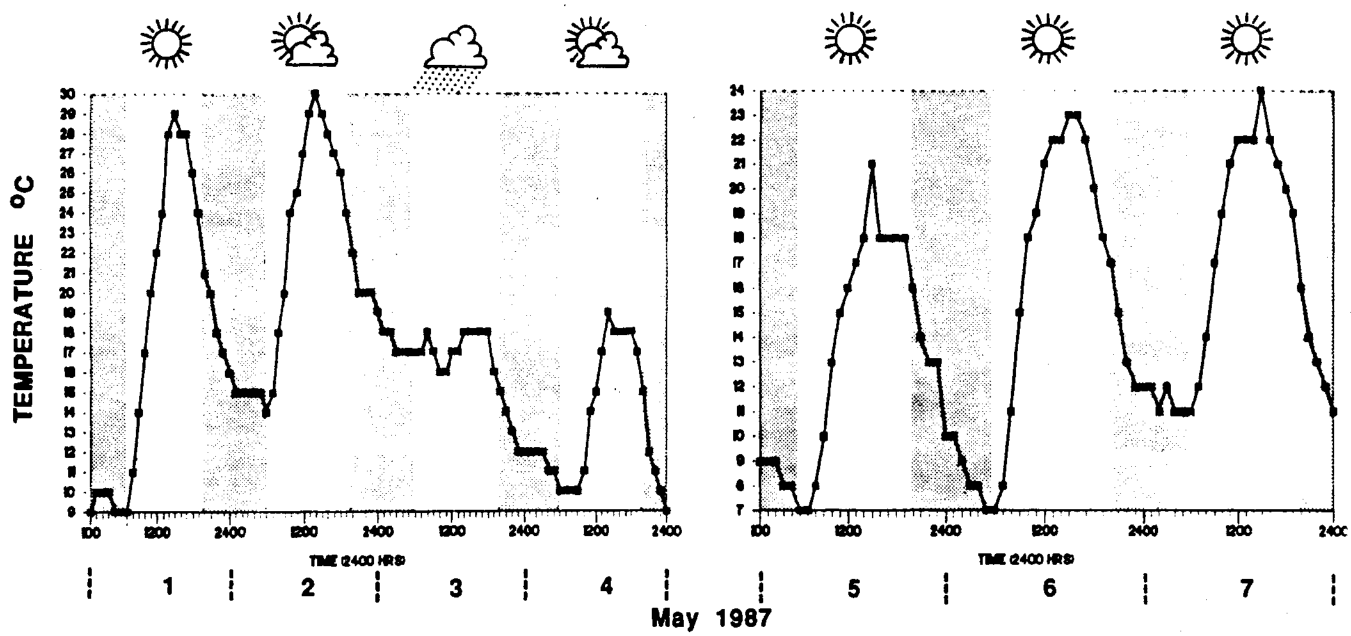

Figure 5. Hourly roost site (beneath bark) temperatures for (*Myotis sodalis*) maternity roost 901 (*Quercus rubra*) from 1-7 May 1987 in relation to selected environmental events. Unshaded portions indicate day length.

Solar warming occurred on 1-2 May; however, rainfall and cool ambient air temperatures during early morning on 3 May prevented normal warming of the roost. The maximum temperature (18 C) during 3 May was only one degree higher than the minimum temperature during the previous night. Wet and devoid of solar exposure, the temperature in the roost site fell to a minimum of 10 C by sunrise on 4 May. Partly sunny conditions on 4 May began drying the tree, but raised the temperature within the roost to only 19 C. Continued evaporative cooling of the roost site later that night resulted in a minimum temperature of 7 C by sunrise on 5 May. Full exposure to solar radiation on 5 to 7 May gradually increased maximum and minimum temperatures within the roost site to higher levels (21-24 C), despite continuing cool maximum (20 to 24 C) and minimum (5 to 8 C) ambient air temperatures.

A mean minimum temperature of 11 C within an *M. sodalis* roost would not significantly prolong gestation by increasing the thermoregulatory energy deficit of females. Thus roost 901 may have remained suitable longer during the summer because adequate air spaces existed beneath the bark, and shading of the site prevented extreme solar heating.

Roost 903: *Quercus rubra*

The roost site, less than two meters above the ground on the west side of this dead tree, was occupied by a transient group of six bats (males and females) on 5 May 1987. A lactating female used tree 903 as a transient roost on 25 May 1988; however, she selected a much higher site on the east side of the tree. The bark covering this site was loose and exposed to the outside by a vertical opening along its southern edge (Appendix A, Figure A-3). Rotting debris filled most of the air spaces under the bark.

Temperatures within this transient roost site ranged from a maximum of 46 C on 22 June (mean maximum = 38 C) to a minimum of 21 C on 18 and 21-22 June (mean minimum = 21.5 C; Figure 6). This roost occurred on a steep SE-facing slope and was exposed to direct sun. Maximum temperatures within the roost were reached by 1500 hrs. Rates of warming (<2 C/hr) were similar to those of roosts with more easterly and southerly exposures. Cloud cover increased gradually on 18-20 June with the passage of a mild cold front, and 11.4 mm of rain fell during early morning on 20 June. Despite this rainfall, the roost site remained relatively dry and responded quickly to solar warming from 21-22 June. Daily maximum temperatures within the roost varied considerably throughout the 6-day period, but minimum roost temperatures remaining consistently above ambient air minima.

High, potentially fatal roost temperatures (e.g., a mean maxima of 38 C) made this site unsuitable for *M. sodalis* during June and later in the summer. Roost temperatures during May could be expected to be more moderate. The western and southern exposure of this roost would allow bats to take advantage of solar warming during cool spring temperatures.

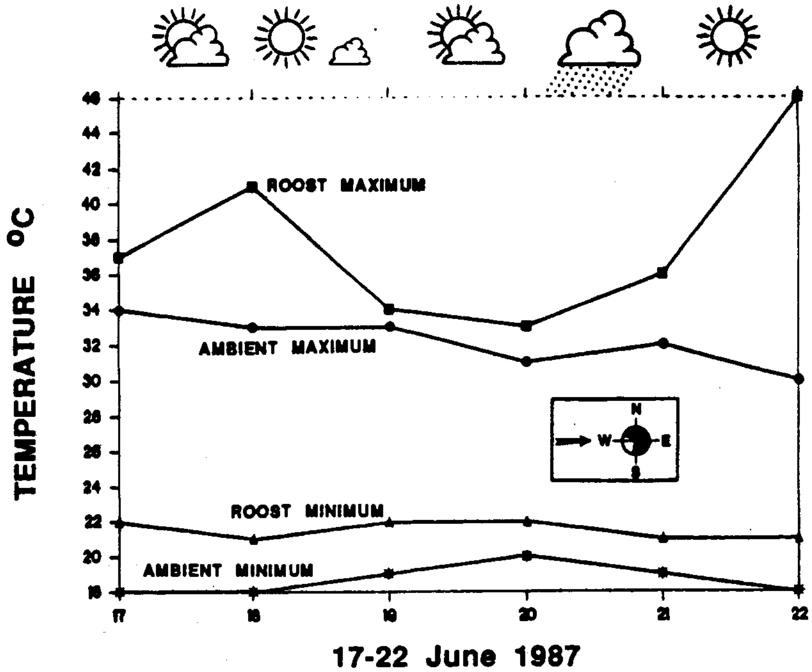

Figure 6. Daily maximum and minimum ambient air and roost site (beneath bark) temperatures for *Myotis sodalis* maternity roost 903 (*Quercus rubra*) from 17-22 June 1987 in relation to selected environmental events. Inset indicates location of roost site (arrow) and shading from the forest canopy (shaded portion of circle).

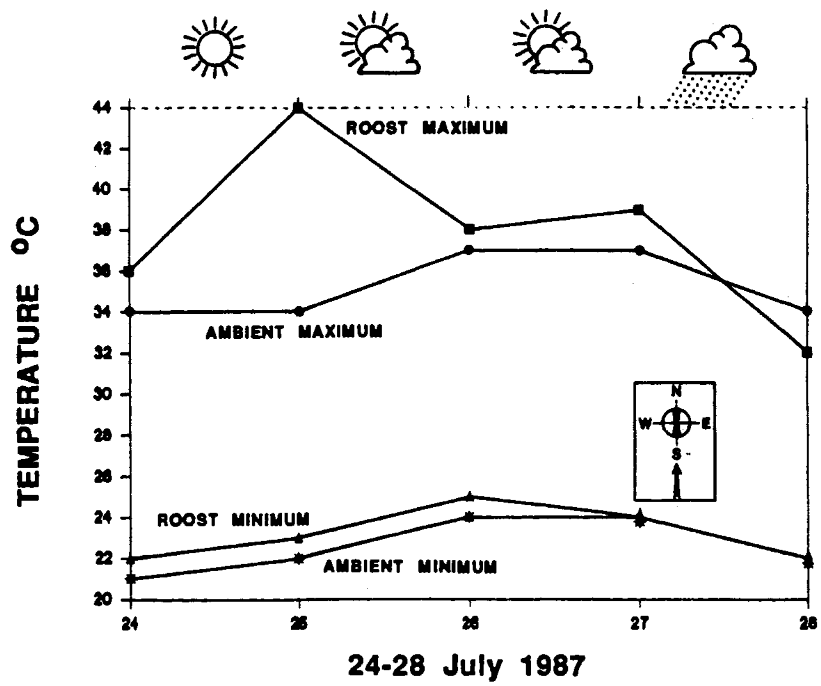

Figure 7. Daily maximum and minimum ambient air and roost site (beneath bark) temperatures for *Myotis sodalis* roost 915 (*Quercus rubra*) from 24-28 July 1987 in relation to selected environmental events. Inset indicates location of roost site (arrow) and shading from the forest canopy (shaded portion of circle).

Roost 915: *Quercus rubra*

The bark covering this roost was open beneath, and the space beneath the bark was very narrow and not conducive to adequate air circulation. This roost, used temporarily by a post-lactating adult female, was located on the south side of a main trunk of a tree and received intense solar radiation throughout the day (Appendix A, Figure A-6).

Temperatures within roost 915 ranged from a maximum of 44 C on 25 July (mean maximum = 38 C) to a minimum of 22 C on 24 and 28 July (mean minimum = 23 C; Figure 7, previous page). Maximum temperatures were usually reached by 1500 hrs, with warming rates >2 C/hr on clear days. The roost site exhibited linear responses to changes in environmental conditions. Temperatures increased steadily from 36 C to 44 C on 24 July, a clear day. Partial cloud cover on 25-26 July resulted in slightly lower maximum temperatures in the roost, but temperatures remained above potentially lethal limits. Rainfall (6.8 mm) on 27 July resulted in a lower (32 C) roost site temperature; however, the maximum temperature had climbed back to 37 C through solar warming during 29 July (not shown in Figure 7). The minimum roost site temperature varied only 3 C during this period. Although high, potentially fatal temperatures during July made prolonged use of this site unsuitable for *M. sodalis*, solar warming during cool periods of early spring could be beneficial to migrating or transient bats.

Roost 921: *Populus deltoides*

The roost was located beneath a large length of thick bark loosely attached to the ESE side of the tree. The outward appearance of this roost was very similar to roost 902 (Appendix A, Figure A-2). Adequate air space between the bark and trunk allowed air to circulate and bats to shift their positions. This roost was occupied by ≥10 bats (including radio-tagged pregnant adult female F263a) that left the roost site by emerging from the open bottom of the bark segment.

Temperatures within maternity roost 921 ranged from a maximum of 27 C on 11 May (mean maximum = 24 C) to a minimum of 7 C on 9 May (mean minimum = 11 C; Figure 8). Maximum roost site temperatures were most often reached by 1300 hrs (Figure 9). Rapid rises in temperatures (>2 C/hr) during early morning (0600-1000 hrs) provided a moderate microclimate for pregnant females through most of the day. This roost site could potentially remain suitable throughout the summer because adequate ventilation and shading would prevent extreme solar heating.

The maximum roost site temperature (27 C) on 11 May was two degrees cooler than ambient air even after four consecutive days of full sun. The sun was partially obscured by clouds on 12 May, resulting in a lower (21 C) temperature within the roost site (Figure 9). Despite the passage of a weak cold front on this date, solar heating on 13 May raised the temperature within the roost to 26 C, somewhat above the ambient air temperature of 24 C. Minimum roost temperatures remained above minimum ambient air

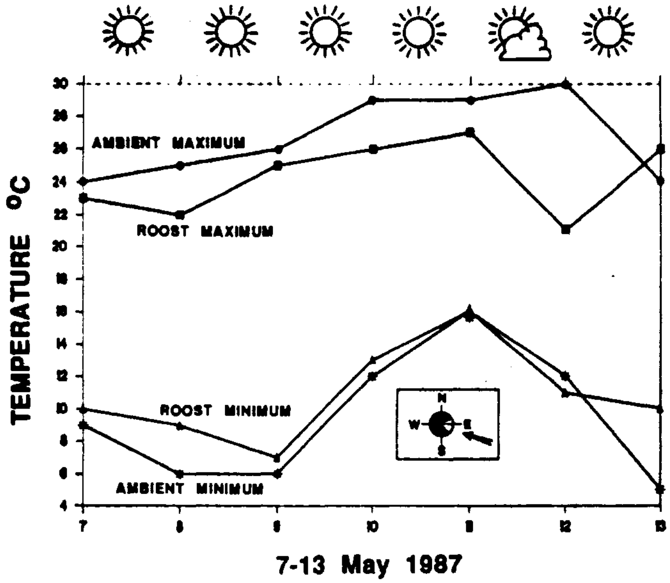

Figure 8. Daily maximum and minimum ambient air and roost site (beneath bark) temperatures for *Myotis sodalis* maternity roost 921 (*Populus deltoides*) from 7-13 May 1987 in relation to selected environmental events. Inset indicates location of roost site (arrow) and shading from the forest canopy (shaded portion of circle).

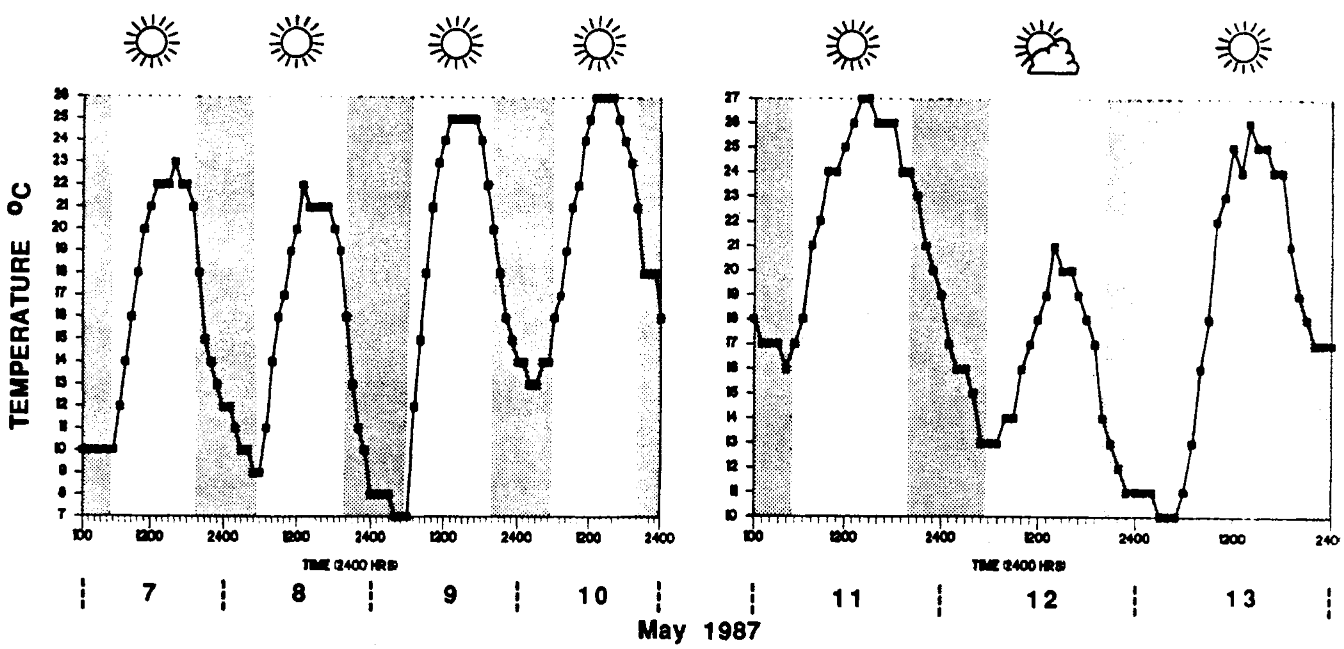

Figure 9. Hourly roost site (beneath bark) temperatures for (*Myotis sodalis*) maternity roost 921 (*Populus deltoides*) from 7-13 May 1987 in relation to selected environmental events. Unshaded portions indicate day length.

temperatures throughout the seven day period, except on 12 May. The absence of or reduction in solar radiation that resulted from increased cloud cover allowed the roost temperature to fall while maintaining higher ambient air temperatures. On 13 May, solar radiation warmed the tree during the day, but convectional cooling during the cloudless night allowed the air temperature to drop while the roost site remained warm.

Shading and adequate air spaces beneath the bark created a favorable microclimate for this roost, which remained suitable for *M. sodalis* throughout the reproductive season. The bark on this tree was destroyed by hail and high winds on 2 June 1987, 28 days after its initial discovery, the first documentation of an occupied roost being destroyed by environmental factors.

Roost 925: *Carya ovata*

This roost, located on the east side of the tree, was shaded from afternoon sun by the trunk and by living trees on its western side (Appendix A, Figure A-9). The bark covering the roost was open at the bottom, with the opening <1 m below the broken, splintered top of the main trunk. A narrow vertical slit from the top of the trunk extended through the roost site and may have been used by some bats. Adequate air spaces beneath the bark allowed movements of bats, and air circulation was potentially good. This roost site was used by the largest number of roosting bats (95) discovered during this study.

Temperatures within the 925 maternity roost ranged from a maximum of 25 C on 14 June, and 18-19 June (mean maximum = 24 C) to a minimum of 10 C on 17 June (mean minimum = 13.6 C; Figure 10). Daily maximum roost temperatures were most often reached by 1400 hrs with solar heating rates of <2 C/hr. Full solar exposure produced an expected heating pattern on 14 June and the warming trend from the nightly minimum temperature was delayed until 1200 hrs on 15 June by an overcast sky during early morning (Figure 11). Reduced solar radiation on 15 June and again on 16 June allowed roost temperatures to drop to 10 C by sunrise on 17 June. Three consecutive days (17-19 June) of full sun returned maximum and minimum roost site temperatures to higher levels. Minimum roost site temperatures were always below minimum ambient air temperatures except on 16 June when the ambient air temperature fell one degree below the roost site temperature.

Roost 925 provided adequate spaces beneath the bark to allow bats to change their positions. A split in the broken, splintered top of the trunk extended vertically through the roost site and provided access to crevice spaces as well as ventilation by creating a convection draft. The tree was exposed to solar radiation but was shaded during early morning by surrounding live trees. This roost was strong structurally and had tenacious, persistent bark that could potentially provide roost sites to *M. sodalis* throughout many reproductive seasons.

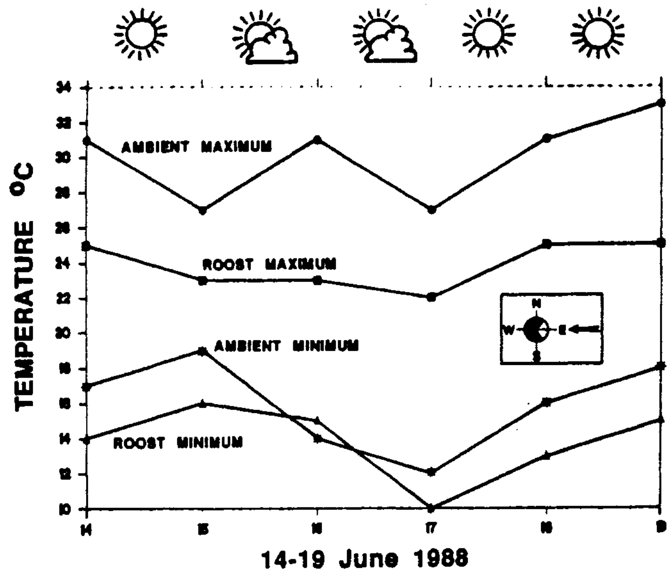

Figure 10. Daily maximum and minimum ambient air and roost site (beneath bark) temperatures for *Myotis sodalis* maternity roost 925 (*Carya ovata*) from 14-19 June 1988 in relation to selected environmental events. Inset indicates location of roost site (arrow) and shading from the forest canopy (shaded portion of circle).

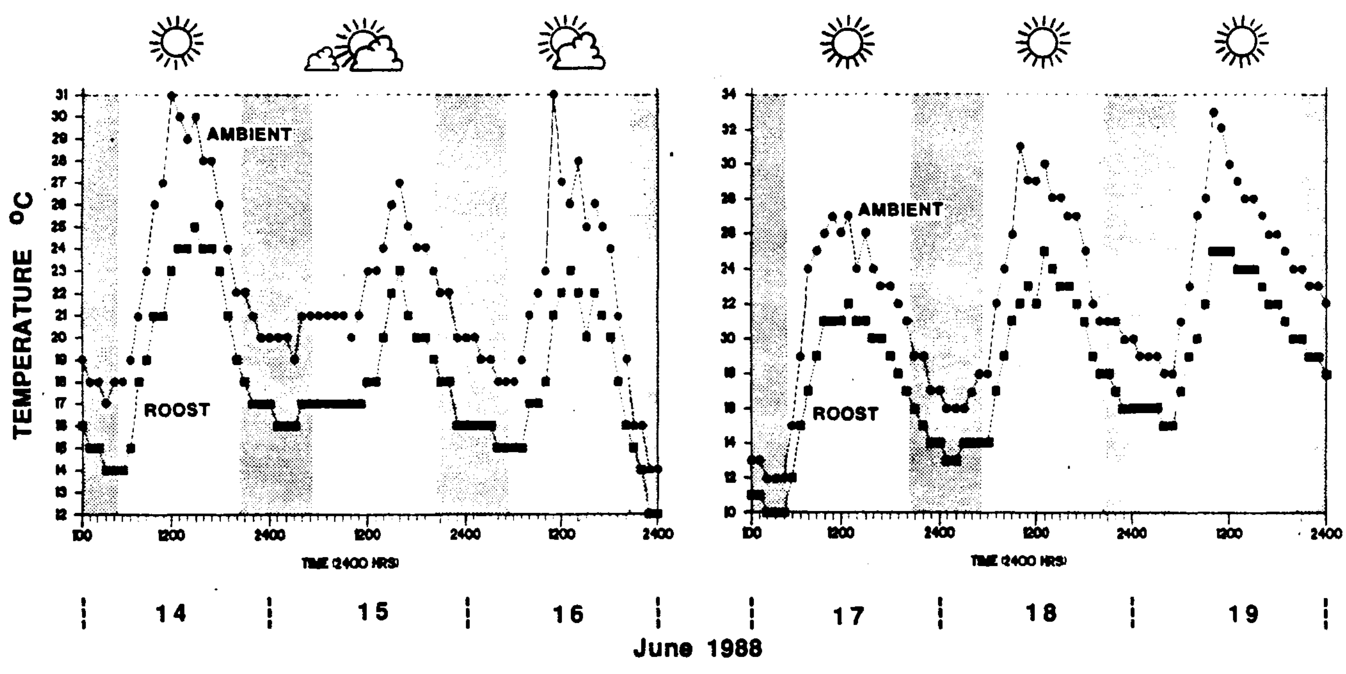

Figure 11. Hourly ambient air and roost site (beneath bark) temperatures for (*Myotis sodalis*) maternity roost 925 (*Carya ovata*) from 14-19 June 1988 in relation to selected environmental events. Unshaded portions indicate day length.

Comparison of Maternity Roosts 921, 925, and 901

Mean rates of changes in temperature at maternity roosts in *Populus deltoides* 921, *Carya ovata* 925, and *Quercus rubra* 901 are given in Figure 12. Temperature changes (±1 C) at the three sites, each in a dead tree, followed very similar patterns. Roosts generally began warming at sunrise (0600 hrs), with temperatures increasing rapidly from 0600 to 1000 hrs on clear days and at a slower rate through 1400 hrs. Roosts began cooling by mid-afternoon (1400-1600 hrs), with an overall mean reduction of >6 C by 2000 hrs.

Microclimates of living *C. ovata* and *A. saccharinum* were not monitored during this study, although bats were found roosting beneath the bark of these species (Appendix, Figure A-7). Although we have no supportive data, living *Carya laciniosa* (kingnut hickory), *Carya ovalis* (sweet pignut hickory), and possibly *Platanus occidentalis* possess extensions of bark tissue similar to those of *C. ovata* and *A. saccharinum*. These species, therefore, are potentially suitable as alternate or transient roosts throughout the reproductive season. Suitable spaces beneath their bark (although limited in size) might well permit bats to roost under temperatures within their tolerance limits.

Distance from Roosts to Selected Features

Mean distances (±1 m) of 56 roost sites (four of the 48 roost trees were used by more than one sex, age, or reproductive group) to roads (paved or nonpaved), streams (perennial or intermittent), original capture sites, and geometric center of foraging ranges (radio-tagged bats) were calculated (Table 2). Distances of roosts to the geometric center of the foraging range of bats monitored by fixed-station telemetry are from the Fishhook Creek study area only; the number of nights of tracking from which the foraging range was calculated is provided.

Roads

Traffic on nonpaved roads was quieter, slower and more infrequent than on paved highways. Distances of roosts from paved highways were significantly ($P \leq 0.05$) greater than from nonpaved roads for all six groups. Roosts of all adult female groups (pregnant, lactating, post-lactating) were farther from paved roads than roosts used by juveniles or adult males. Roosts used by reproductively active females (pregnant or lactating) were rarely <500 m from paved highways but lactating adult female F444 used roost 911 and 913, each on a single occasion. Located 145 m and 210 m, respectively, from the highway, both sites were in densely forested upland slopes. Additionally, roost 901, used by 18 pregnant adults during 1986, was 450 m from the highway. The remaining 21 roost sites occupied by pregnant or lactating adults occurred >700 m from paved highways.

One roost (910), used twice by nomadic adult male M462 with no fixed home range, was only 95 m from Illinois Route 104 (see Figure 3). Four other roosts used by individual adult males (002, 003, 004, 912) were <240 m from a paved highway. Roosts used by juveniles were always >660 m from paved highways.

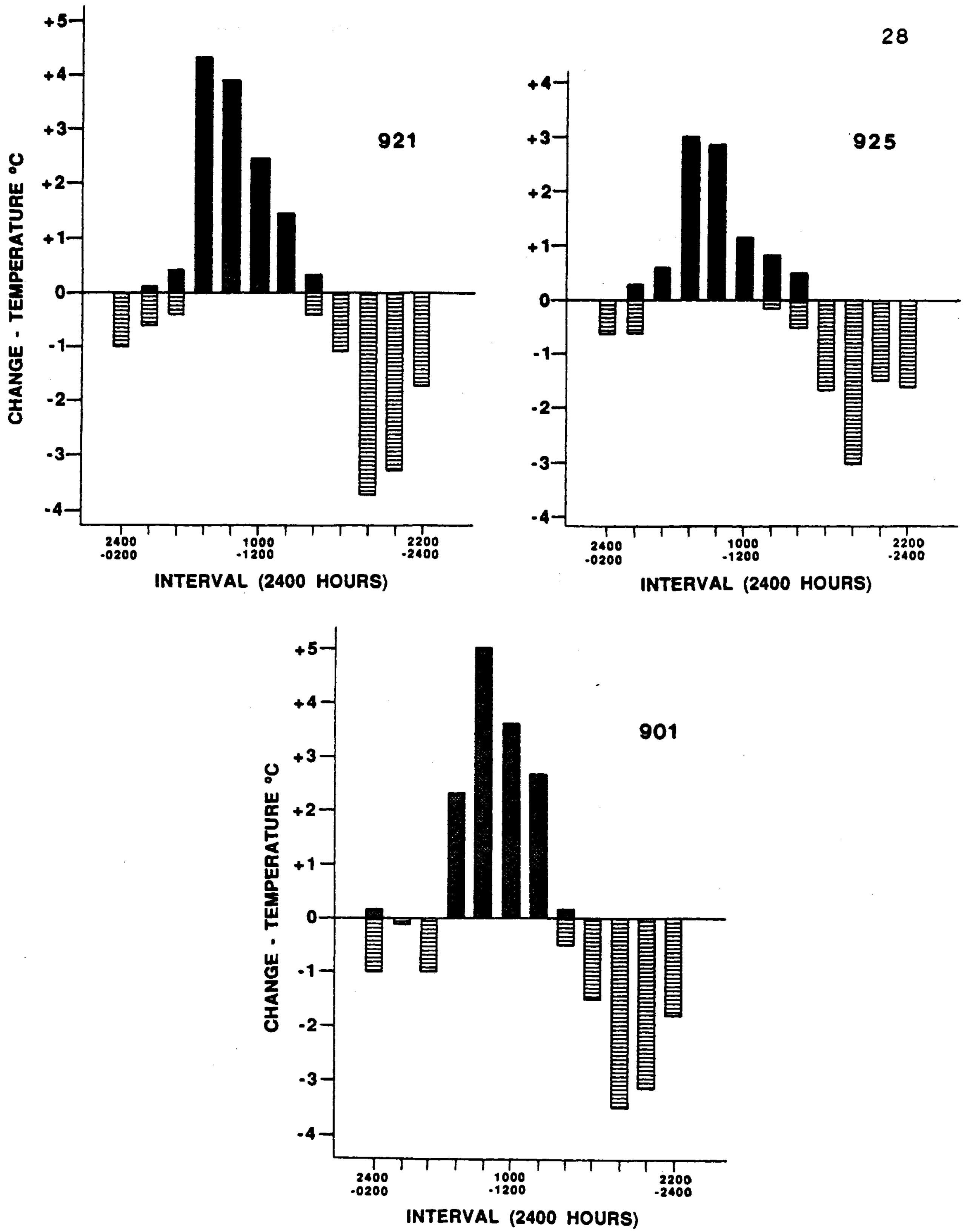

Figure 12. Mean change in roost site temperature for *Populus deltoides* maternity roost 921 (7-13 May 1987), *Carya ovata* maternity roost 925 (14-19 June 1988), and *Quercus rubra* maternity roost 901 (1-7 May 1987).

Table 2. Mean distance (m) of 56 *Myotis sodalis* roost sites to selected natural and man-made features, original capture sites, and the geometric center of the foraging range compiled by sex, age, and reproductive groups (six of the 48 roost trees were used by more than one group).

AGE/ REPRODUCTIVE GROUP (x=roosts)	DISTANCE (M) PAVED HWY	NONPAVED ROADS	*PERENNIAL STREAM	*INTERMITTENT STREAM	ORIGINAL CAPTURE SITE (x=bats)	GEOMETRIC CENTER FORAGING RANGE (x=nights)
Pregnant (9)	1621	774	590	116	1305 (5)	1054 (5)
Lactating (15)	1409	605	842	123	1259 (7)	1035 (12)
Postlactating (3)	1560	663	1627	51	2932 (3)	2597 (2)
Juvenile Female (5)	827	706	1797	113	698 (2)	251 (3)
Juvenile Male (7)	965	749	2116	149	1040 (4)	544 (5)
Adult Male (17)	930	564	871	193	1082 (5)	557 (9)

*Determined from Fishhook Creek 7.5 minute U.S. Geological Survey quadrangle

Streams

Distances from roosts to streams indicate that roost sites used by all groups were closer to intermittent streams (combined mean = 124 m) than to any other feature studied. The greatest distance from an intermittent stream was 230 m (roost 925); however, one roost used temporarily by a pregnant adult was 420 m from an intermittent stream. Roost 901 occurred 2 m from an intermittent stream and maternity roost 921 was 20 m from an intermittent drainage. Four other maternity roosts (001, Jackson County; 006, Saline County; 007, Ford County; and 008, Henderson County) occurred <190 m from intermittent streams. Both roosts selected by post lactating adult F342 were <2 m from intermittent drainages. Ten of the 17 roosts used by adult males were ≤100 m from intermittent streams and all roosts used by juveniles were <210 m from intermittent streams.

Pregnant adult bats (n = 7) more frequently than any other group selected roosts closer to perennial streams. Maternity roost (921), used by pregnant F263a, was 20 m from Fishhook Creek in a <1.2 ha floodplain forest. Roosts 922 and 923, also used by F263a, occurred 35 m and 30 m respectively from Fishhook Creek within the same small floodplain forest. Furthermore, juvenile female F122a (which was renamed lactating adult F083 in 1988) roosted in tree 902 during 1986; a roost that was 20 m from Fishhook Creek and within 30 m of roosts 921, 922, and 923, all within this same floodplain forest. Roost 925, however, contained the largest maternity colony and occurred 2525 m from Fishhook Creek. The radio-tagged pregnant F363 that was tracked to roost 925 returned nightly (18-24 May 1988) to Fishhook Creek to forage. Roosts used by pregnant bats other than those mentioned above occurred within 875 m of perennial streams. Post lactating F342 selected roosts that were 1350 m and 2790 m from Fishhook Creek; however, she returned consistently to forage in an area that encompassed Fishhook Creek.

One adult male (M323) roosted in three trees in Johnson County that were >2500 m from a perennial stream (Cache River); however, the remaining 14 roosts used by adult males were <870 m from a perennial stream (Fishhook Creek). Juvenile male M424 selected roost 937, only 260 m from Fishhook Creek. The remaining seven roosts used by juveniles, however, were substantially farther (>2000 m) from perennial streams than the roosts of any other group.

Foraging Ranges

Previous studies by Humphrey *et al.* (1977) determined that individuals from an *M. sodalis* maternity colony in eastern Indiana foraged along an 0.82-km segment of perennial stream. On one occasion, they recorded a flight distance of 290 m for a pair of bats traveling from their roost to a foraging site.

Our studies indicated greater movements from their roosts of certain sex, age, and reproductive groups of *M. sodalis*. Post-lactating F342 traveled further from her roosts to reach her preferred foraging site (based on six nights of foraging) than any other radio-tagged bat. The first roost (915) used by F342 was 2000 m from the geometric center of her foraging range; however, she moved (after being disturbed) to a second roost (917) that was 3193 m from the same geometric center. Despite this additional distance and the disturbance, she returned to forage within the same area (mean=253 ha).

Distances that pregnant and lactating bats traveled from their roosts to their preferred foraging areas were very similar to each other; both groups traveled further to their foraging sites than did either juvenile males and females or adult males. One lactating adult (F484) traveled a mean distance of 978 m (based on four nights of tracking) to her foraging area. The mean distance traveled by the remaining four lactating adults was 1064 m. Juvenile males and females and adult males traveled only about half the distance that adult females traveled. Juvenile females had smaller foraging ranges (mean = 37 ha) than any other group. Their ranges were also located considerably closer to their roosts than those of other groups.

Original Capture Sites

Post-lactating adults were more likely to be captured farther from their roosts than bats in any other group. For example, post-lactating F342 initially selected roost 915, located 2675 m from her original capture site on Fishhook Creek. After being disturbed, however, she moved to a roost that was 4060 m from her capture site, the greatest distance between roost and original capture site traveled by any radio-tagged bat. Another post-lactating adult captured over a perennial stream in Macoupin County selected a roost (005) 2060 m from her capture site. Mean distances between roosts used by pregnant and lactating adults and original capture sites were similar to each other and greater than mean distances traveled by juveniles and adult males.

A pregnant adult was captured over a stream (which was relocated for surface mining) in Saline County 3900 m from her maternity roost. Maternity roosts 925 at Fishhook Creek was 2525 m from the site where pregnant F363 was originally captured. Pregnant F263a used three roosts (921, 922, 923) during early May 1987, all within 410 m of her original capture site. A lactating adult captured in Henderson County was tracked to a roost (008) that contained 18 other bats and was located 1650 m from where she had been captured. During 1988, lactating F083 (known as juvenile F122a in 1986) selected five roosts ranging from 650-1275 m from her 1988 capture site on Fishhook Creek. The 1986 capture site was 1175 m from the roost used that year by juvenile F122a and <800 m upstream from the site where she was captured as lactating adult F083 in 1988.

Although only two juvenile females were captured at sites other than their roosts, the mean distance (698 m) from the four roosts they used to the netting sites was considerably smaller than the distances of other groups. Two of four juvenile males selected roosts that were >2000 m from their original capture sites. One juvenile male subsequently selected three roosts that were within 587 m of the roost from which he was originally captured. The greatest distance from a roost used by an adult male to its original capture site was 2975 m, and that distance was traveled by nomadic adult M323, who had been captured over the Cache River, Pulaski County. One adult male (M462) selected a roost 115 m from his capture site of the previous night and subsequently selected five roosts, all <500 m from his original capture site.

Loyalty to Summer Roosts

We expected *M. sodalis* to exhibit philopatry for its summer roosts because the species had demonstrated strong loyalty to hibernacula (LaVal and LaVal 1980). Cope *et al.* (1974) and Humphrey *et al.* (1977) were first to present information concerning philopatry by *M. sodalis* for summer roosts and foraging ranges. Such complicated factors as relative abundance and permanency of roost sites, roost site microclimate (e.g., temperature and moisture), food resources, predators, and human disturbance affect roost philopatry (Kunz 1982). Because population declines of *M. sodalis* have been directly attributed to human disturbance, its roosting behavior during our study was probably affected by our activities at the roost. For this reason, we limited disturbance (capturing, banding, and radio-tagging) primarily to capture sites most often located in foraging areas away from the roost.

Two types of philopatry (fidelity) for the Fishhook Creek study area are discussed below; summer fidelity, or the revisitation of bats (marked or unmarked) to known roosts during a single summer, and philopatry, or the return of marked (banded) bats to the Fishhook Creek watershed and/or revisitation to specific roosts used during previous summers.

Single Summer Fidelity

Nonreproductive adult male M383 initially roosted in *Q. stellata* roost 905 (Appendix, Figure A-4) on 1 May 1987 (Table 3). This male returned to the 905 roost site during 6-7 May; however, he selected roost 904 on 4 May and 903 (Appendix A, Figure A-3) on 5 May. Male M383 again selected a new roost (906: Appendix, Figure A-5) on 8 May. This highly nomadic bat was the only individual to return to the roost he had used initially after having used other sites. Another male, a juvenile, selected roost site 930 for six consecutive days, thereby exhibiting fidelity for a roost longer than any other bat we studied. Pregnant adult F263a shared *P. deltoides* roost 921 from 5-8 May 1987 with three other bats before it was destroyed by hail, heavy rain, and high wind on 2 June. This female had selected two separate *A. saccharinum* roosts (922 and 923) before choosing roost 921. Lactating F083 (known as F122a during 1986) selected five (903, 924, 926, 927, 928) roost sites from 17 May through 25 May 1988 but chose to revisit only one (928).

Table 3. Summer fidelity and philopatry data for *Myotis sodalis* recaptured at Fishhook Creek, Pike and Adams counties, Illinois, from 1986 through 1989.

ROOST	DATE	*BAT ID	SEX	AGE	**REP. COND.	TOTAL NO. BATS
901	14 May 1986	na	F	A	PG	3
	"	na	(not captured)			15
	1 May 1986	na	(guano only)			?
903	5 May 1987	M383	M	A	NR	1
	"	na	F	A	PG	1
	"	na	(not captured)			4
	25 May 1988	F083	F	A	L	1
905	1 May 1987	M383	M	A	NR	1
	19 Sept 1989	na	F	A	PL	1
	"	na	(not captured)			7
920	23 June 1987	M181	M	A	NR	4
	23 May 1988	na	F	A	PG	1
	"	na	M	A	NR	4
925	17 May 1988	F363	F	A	PG	1
	"	na	(not captured)			57
	13 June 1988	F282, F163	F	A	L	2
	"	na	(not captured)			93
	20 Sept 1989	na	F	A	NR	8
	"	na	M	J	NR	1
	"	na	M	A	SC	3
	"	na	M	A	NR	1
	"	na	(not captured)			37

*na=nontagged bats
**PG=pregnant; NR=nonreproductively active; L=lactating; PL=postlactating; SC=scrotal

Perhaps the best example of summer roost fidelity in *M. sodalis* was exhibited by a maternity colony inhabiting *Carya ovata* roost 925 (Table 3: Appendix, Figure A-9). A pregnant adult female (F363) was first tracked to this roost on 17 May 1988. This female and 58 other individuals used the roost site until at least 20 May, but had abandoned the site by 23 May. Observations of the roost at dusk on 13 June resulted in an exit count of 95 individuals. This maternity population (three lactating bats captured from the roost on 13 June) used roost 925 until 24 July, after which no bats were present. This roost was also occupied by *M. sodalis* during 1989 (discussed below).

Several roosts (924, 933, and 938) were revisited by different individuals within the same summer. During 1988, a dead *Acer saccharinum* roost 924 (Appendix, Figure A-8) was used as a roost by a lactating adult (F083) on 17 May, and by another lactating adult (F484) on 16 June. It was not determined if the exact roost site used by F083 was revisited by F484. Also in 1988, a dead *Quercus rubra* (933) was used on three separate occasions by three individual bats; a lactating adult (F282) on 21 June, a juvenile female (501) on 28 July, and a juvenile male (M721) on 4 August. Two of these bats (F501 and M721) simultaneously roosted in another *Q. rubra* (938), less than 9 m from roost 933, with nine other bats from 2-3 August.

Multiple Summer Fidelity

Unlike single summer fidelity, we have no data that directly documents true philopatry of *M. sodalis* for specific summer roost sites; however, three banded bats (one adult female, one juvenile female, and one adult male) annually returned to the Fishhook Creek watershed and to selected roosts that were very near their original roosts. We were able to document that roosts used one summer were used as roosts by different individuals during following summers (Table 3).

As a species, *M. sodalis* displayed philopatry for four known roosts (903, 905, 920, and 925). Roost 901 (Appendix, Figure A-1), the first maternity roost of *M. sodalis* discovered in Illinois, was revisited by bats during 1987; however, we were unable to verify that the bats were *M. sodalis*. On 5 May 1987, a pregnant adult, a radio-tagged adult male (M383), and four bats that escaped handling were clustered beneath the bark in a roost site 2 m above the ground in tree 903 (Appendix A, Figure A-3). A radio-tagged lactating adult (F083) roosted beneath the bark of 903 on 25 May 1988 in a site much higher above the ground than the 1987 site. The roost selection of F383 during 1987 previous to the 5 May 1987 occasion is not known; however, F083 (known as nonreproductive juvenile F122a in 1986) roosted in *P. deltoides* (902) with ten other bats in early September 1986. Roost 902 (Appendix, Figure A-2), used in 1986, was located in a forested floodplain 1.0 km WNW from the upland roost (903) she used in 1988.

Roost 905 (Appendix, Figure A-4), a dead *Q. stellata*, was one of four roosts used from 1 May 1987 through 8 May 1987 by radio-tagged adult male M383. This upland roost was examined on 19 September 1989 and found to contain a post-lactating adult and seven bats that escaped handling; however, the site used by these eight bats differed slightly from the site used in 1987.

On 23 June 1987, adult male M181 and three other adult males were discovered beneath a small piece of protruding bark on roost 920 (Appendix A, Figure A-7), a living *C. ovata*. This same piece of bark was examined on 25 May 1988, when a pregnant adult and four adult males were captured.

The largest maternity population of *M. sodalis* (95 individuals) thus far reported for the species was discovered in dead *C. ovata* roost 925 (Appendix, Figure A-9), during 1988. This roost was obviously well known because at least 50 *M. sodalis* (adult females, adult males, and a juvenile male examined) were discovered when it was re-examined on 20 September 1989. During 1989, the bats used a site 2 m lower than the 1989 site.

<u>Inherent and Environmental Attrition of Roosts</u>

The quantity of loose bark on a tree can be used as an indicator of how suitable that tree is for roosting structures for *M. sodalis*. The ranking system (see Methods) we developed enabled us to compare the suitability of trees not known as roosts of *M. sodalis* to that of trees known to have been selected as roosts. This system also allowed us to access roost attrition. Each of the 39 roost trees in Pike and Adams counties was re-examined each summer after its discovery in order to assess attrition.

Of the 34 dead roost trees within the Fishhook Creek study area, 31 initially exhibited a high potential to provide bark for roosting structures (Table 4). Two of the 34 roosts were ranked initially as offering a moderate amount of structure and one tree had no loose bark. The two living *C. ovata* roosts had high bark potential, but the three living *A. saccharinum* offered moderate to low potential. Only dead *S. albidum* and *P. deltoides* provided cavities for roosts; however, all three living *A. saccharinum* contained cavities used by bats. By the second summer following their discovery, eighteen (53%) of the 34 dead roost trees either experienced a reduction (n = 8) in suitability or became completely unsuitable (n = 10) for roost structures. The potential of the five living roost trees to provide bark roosts did not change from one summer to the next. Of the 21 roost trees identified in 1987, four (19%) were no longer suitable as roosts during 1988. Two (13%) of the 16 roost trees discovered in 1988 were no longer suitable during 1989. Regardless of reduction or complete loss in the potential of a tree to provide bark roost structures, 12 (31%) of the 39 roost sites occupied by *M. sodalis* were unavailable the summer following their discovery, and 9 (33%) of the 27 remaining roost sites were unavailable by the second summer.

Table 4. Attrition of *Myotis sodalis* roost trees, by species, within the Fishhook Creek study area, Adams and Pike counties, Illinois, using availability of roost site and yearly suitability rankings as attrition criteria.

		1986			1987			1988			1989		
ROOST	ORIG. SITE	*ROOST SITE COND	TREE +SUIT RANK	NO. BATS	*ROOST SITE COND	TREE +SUIT RANK	NO. BATS	*ROOST SITE COND	TREE +SUIT RANK	NO. BATS	*ROOST SITE COND	TREE +SUIT RANK	NO. BATS
Acer saccharinum													
922	bark				org	2/C	1	nc	2/C	0	nc	2/C	0
923	bark				org	1/C	1	nc	1/C	0	xx	0/C	0
924	cavity							org	3	1		down	
926	bark							org	1/C	1	nc	1/C	0
Carya cordiformis													
911	bark				org	3	1	nc	3	0		down	
934	bark							org	3	1	nc	3	0
Carya ovata													
919	bark				org	3	1	nc	3	0	nc	3	0
920	bark				org	3	4	nc	3	5	nc	3	0
925	bark							org	3	95	nc	3	50
931	bark							org	3	1	nc	3	0
935	bark							org	3	14	nc	3	0
Populus deltoides													
902	bark	org	3	10	no potential			no potential			no potential		
917	bark				org	2	1	no potential			no potential		
921	bark				org	3	3	no potential			no potential		
932	bark							org	3	1	xx	1	0
Quercus alba													
939	bark							org	3	15		down	
Quercus imbricaria													
908	bark				org	3	1	xx	1	0		down	
Quercus rubra													
901	bark	org	3	18	nc	3	?	xx	2	0	xx	2	0
903	bark				org	3	6	nc	3	1	xx	3	0
913	bark				org	3	1	nc	3	0	nc	3	0
915	bark				org	3	1	nc	3	0	nc	2	0
927	bark							org	3	1	nc	3	0
928	bark							org	3	1	xx	1	0
933	bark							org	3	9	nc	3	0
936	bark							org	3	1	nc	3	0
938	bark							org	3	11	xx	3	0

* org=original discovery; nc=no change; xx=not available
\+ 1=low; 2=moderate; 3=high; C=cavity

Table 4. (concluded)

ROOST	ORIG. SITE	1986 *ROOST SITE COND	1986 TREE +SUIT RANK	1986 NO. BATS	1987 *ROOST SITE COND	1987 TREE +SUIT RANK	1987 NO. BATS	1988 *ROOST SITE COND	1988 TREE +SUIT RANK	1988 NO. BATS	1989 *ROOST SITE COND	1989 TREE +SUIT RANK	1989 NO. BATS
Quercus stellata													
904	bark				org	3	1	nc	3	0	xx	3	0
905	bark				org	3	1	nc	3	0	nc	3	8
929	bark							org	3	2	nc	3	0
Sassafras albidum													
918	cavity				org	0/C	4	nc	0/C	0	nc	0/C	0
Ulmus rubra													
906	bark				org	3	1	nc	3	0	xx	3	0
907	bark				org	3	1		down			down	
909	bark				org	3	1	nc	2	0	xx	1	0
910	bark				org	3	1	nc	3	0	xx	2	0
912	bark				org	3	1	xx	1	0		down	
914	bark				org	2	1		no potential			down	
916	bark				org	3	1	nc	3	0		no potential	
930	bark							org	3	1	nc	2	0
937	bark							org	3	1	xx	2	0

* org=original discovery; nc=no change; xx=not available
\+ 1=low; 2=moderate; 3=high; C=cavity

Of the ten species of roost trees (either dead or living) found within the Fishhook Creek study area, *P. deltoides*, *Q. rubra*, *Q. stellata*, and *C. ovata* were the species with the thickest bark (Table 1). These three species also had the most tenacious bark (especially for dead trees) and exhibited the strongest tendencies to retain known bark roost sites and potential bark roost structures from summer to summer. The significance of three of these three species for *M. sodalis* is evident if we recall that *Q. rubra* (901 and 903), *Q. stellata* (905), and *C. ovata* (920 and 925) were the only roost trees revisited by *M. sodalis* during different years (see Multiple Summer Fidelity).

By 1988 (two years after its discovery), bark had completely fallen from a 2-m segment of the main trunk of *Q. rubra* 901, including the original roost site; nevertheless, the tree's overall potential to provide bark suitable for roosting structures dropped to only moderate. In fact, 901 retained a moderate amount of bark roost structure through 1989. *Carya cordiformis* can be thickly barked (1.2 cm) and has the same exfoliation patterns as *C. ovata*. Although our sample was small, *C. cordiformis* were an important element of potential roost availability. Dead *Q. imbricaria* have inherently thick and tenacious bark, making them potential candidates for roost structures. *Quercus alba*, however, probably had less potential due to bark thinness and exfoliation characteristics.

Although *Ulmus rubra* was frequently (26%) used as a roosting site by *M. sodalis*, it exhibited almost predictable yearly reductions and complete losses in bark potential. The bark of dead *U. rubra* was thin (0.8 cm) and usually hung from the tree in large loose sheets that were easily dislodged, especially if rain-soaked (heavier) and wind-blown (Appendix, Figure A-5). More than any other species, *U.rubra* tended to be rotten at the base of the trunk and, as a result, more prone to windfall. Three of the nine *U. rubra* previously used as roosts were no longer standing by the third summer following their discovery.

Although *P. deltoides* had thick (2.1 cm) bark, three of the four *P. deltoides* had completely lost their bark the year following their discovery. The potential of the remaining tree was reduced from high to low within the summer following its discovery. None of the four *P. deltoides* retained its original roost sites; in fact, *P. deltoides* 902 (Appendix, Figure A-2), discovered in September 1986 had lost all of its bark by early April 1987. Roost 921 was destroyed by hail, heavy rain, and high wind 28 days after its discovery. Of the remaining species, three living *A. saccharinum* offered little or no loose bark, but provided cavity roosts for *M. sodalis*.

<u>Disturbance and Alteration of Roosts by Humans</u>

Practically all roosts of *M. sodalis* reported prior to this study had been discovered as a direct result of tree destruction. In Indiana, the first roost of *M. sodalis* ever reported (Cope *et* *al.* 1974) had been destroyed during agricultural clearing, and another was discovered only after it had been cut for firewood (Whitaker, pers. comm.). A roost site reported by Humphrey *et al.* (1977) had been destroyed during utility right-of-way clearing.

Disturbance and Alteration Through Selective Cutting

Selective cutting was conducted within an area (approximately 50 ha) of upland and floodplain forests in the Fishhook Creek study area during 1987 (Figure 13). Although eight roosts occurred within the harvested area radio-tracking demonstrated that *M. sodalis* continued to roost (and forage) within the harvested area (Figure 14). Bats revisited roosts 901 and 903 during the summers following the harvest. Long-term effects of selective tree removal on the attrition rate of these roosts are not yet known. Four roosts (904, 905, 906, 931) outside the harvest area will be compared to eight roosts within the harvested area to assess the potential impact of selective cutting.

Disturbance and Alteration as a Result of This Study

Climbing roost trees with ladders, placing thermocouple probes beneath bark, conducting tenth-hectare plot vegetational analyses, and removing (capturing) bats from roost sites caused varying degrees of disturbance. The behavior of bats following such disturbances was dependant upon the type of disturbance. For example, quietly climbing trees to pinpoint a radio-tagged bat's position beneath the bark seldom disturbed roosting bats. Even when bats detected our presence, they seldom fled the roost. Vegetation analyses were usually conducted when bats were not present in the roost. The placement of thermocouple probes into a roost site beneath the bark disturbed roosting bats but seldom caused them to flee the site. Most probes were placed beneath the bark only after the bats had left the roost to forage.

Bats were removed from three roosts during 1987 and from two roosts during 1988 and again in 1989. Removing bats to band, weigh, and attach or remove transmitters usually caused them to flee, despite our efforts to contain them in the roost after handling. The removal of bats from beneath loosely attached pieces of bark sometimes caused the bark to become dislodged and the roost site to be altered or destroyed. After Humphrey *et al.* (1977) had trapped *M. sodalis* as they emerged from the roost, they reported a decrease in population at the roost site. For these reasons, we removed bats from their roosts only if they could not be captured elsewhere by less intrusive methods.

Emergence Behavior

We recorded the emergence behavior of 190 *Myotis sodalis* from four roosts (three maternity roosts and one juvenile roost) on six evenings (17 May 1988, 13 June 1988, 11 July 1989, 18 July 1988, and 2 and 3 August 1988). More bats (68% of the total observed) emerged from their roosts between 30 and 45 minutes after sunset (MAS) than during any other period (Figure 15). Initial emergence times varied from six MAS on 6 July to 29 MAS

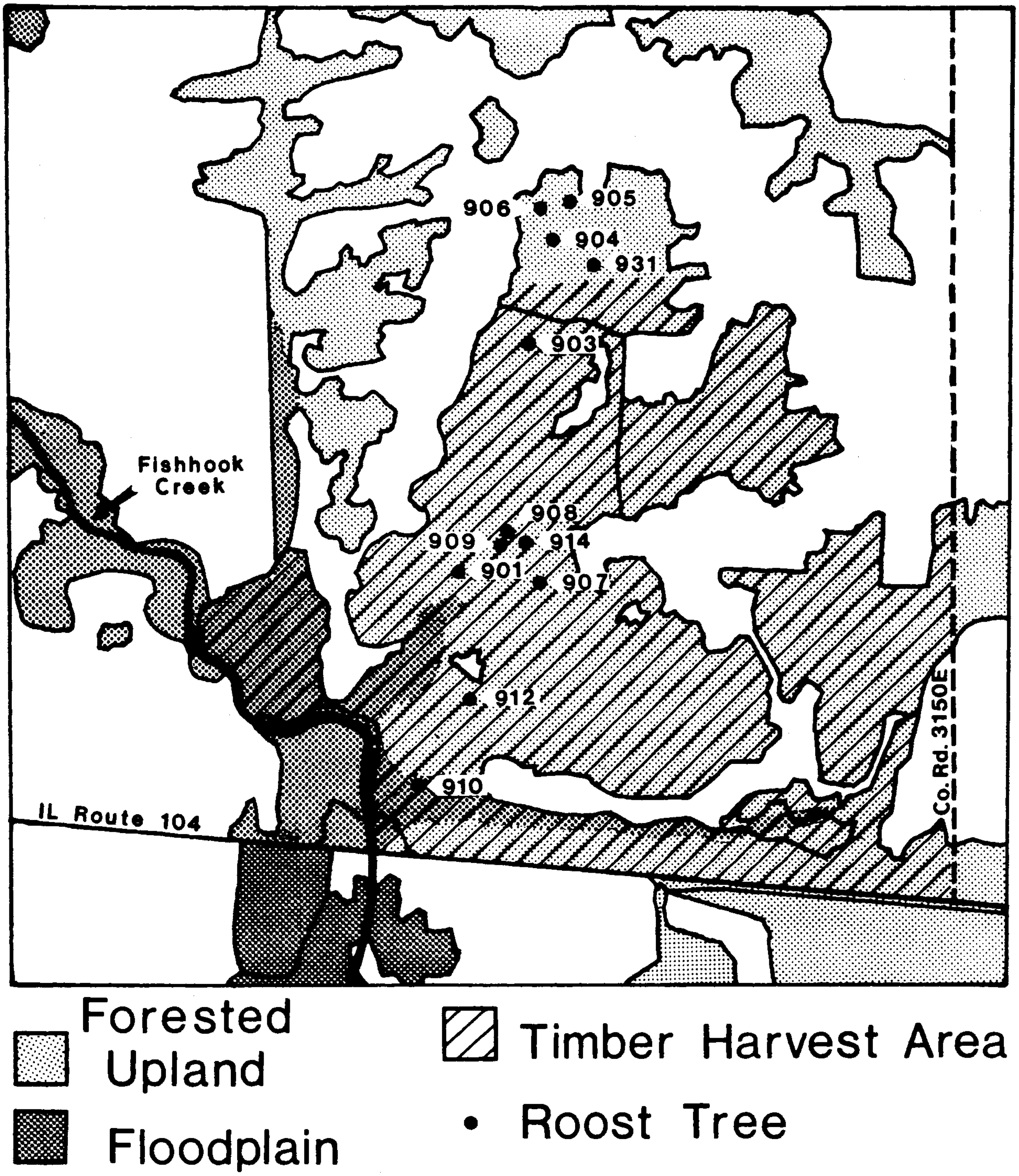

Figure 13. Location of 12 *Myotis sodalis* roost trees in a timber harvest area (selective removal) within the Fishhook Creek study area, Pike and Adams counties, Illinois, during 1987.

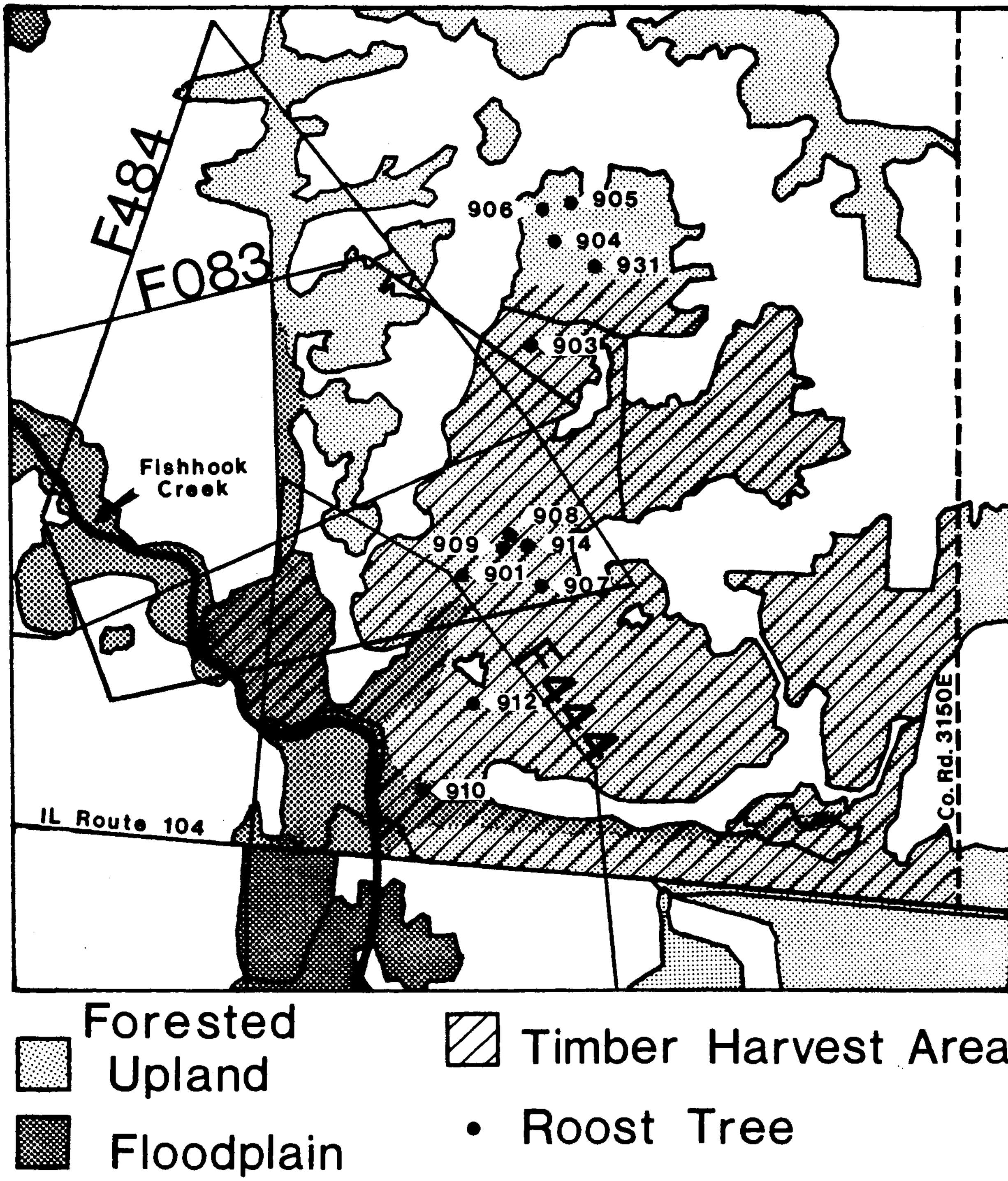

Figure 14. Foraging ranges of lactating adults F444 (24 June 1987), F484 (21 June 1988), and F083 (24 May 1988) in relation to the timber harvest area within the Fishhook Creek study area, Pike and Adams counties, Illinois.

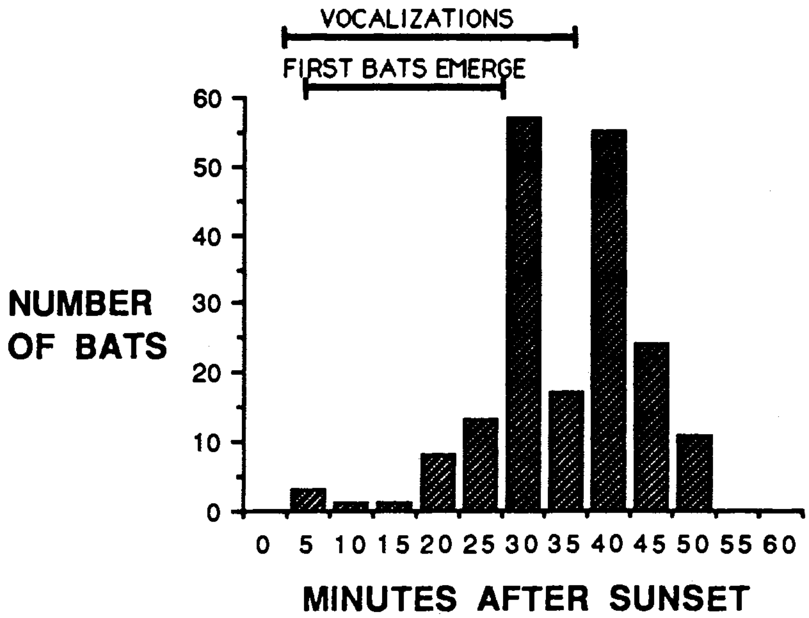

Figure 15. Times of emergence of 190 *Myotis sodalis* from four roosts (maternity roosts 007, 008, and 925 and juvenile roost 938) as observed during six evenings in 1988 and 1989.

on 17 May (mean = 21 MAS). Vocalizations, accompanied by restlessness within the roost, began prior to the first emergence and were more pronounced during July (see Checking Behavior below).

Rates of emergence varied from 1 bat/5 mins to 11 bats/5 mins. Large numbers of bats emerging between 30-35 MAS (57 bats) and 40-45 MAS (55 bats) can be attributed to emergence counts at maternity roost 925 on 17 May when 58 bats were present and on 13 June when 95 bats were present. Bats emerging later than 55 MAS could not be counted because of darkness; however, our observations indicated that most bats had usually left the roost by this time.

Typical Emergence

Although the number of *M. sodalis* that emerged from roost 925 was larger than that from any other colony we studied, the emergence behavior there was typical of that observed at other roosts during the same period. On 17 May 1988, radio-tagged pregnant F363 and 57 other bats emerged from this roost site. On 13 June 95 bats (all presumed adult females) emerged from the site. During the 17 May observation, the first bat emerged at 29 MAS but by 36 MAS 41 more bats (including F363) had left the roost. Sixteen more bats emerged between 36 and 42 MAS. Vocalizations and restlessness within this roost began at six MAS, 23 minutes before the first bat emerged. Once the May emergence began, bats flew quickly away from the roost and did not circle near it or reenter it. Bat F363 had left this roost at 29 MAS and was foraging in her usual area, 2.4 km east of the roost by 53 MAS. During 13 June, the first bat emerged at 22 MAS, eight minutes after the first vocalizations were heard within the roost. By 41 MAS, 60 bats had emerged; 35 more bats emerged between 41 and 56 MAS. As in May, bats left the roost site immediately and did not circle or reenter the roost.

Checking Behavior

A type of circle and reentry behavior, initially described as "checking behavior" for *Antrozous pallidus* (Vaughan and O'Shea, 1976), was first reported for *M. sodalis* by Humphrey *et al.* (1977) in an eastern Indiana colony. During mid-July and early September, they observed highly vocal bats immediately upon emerging from the roost to circle close to the roost site, to land on it, and often to reenter. We observed this behavior in radio-tagged lactating F138 and in 17 other bats as they emerged from a roost in *Ulmus rubra* 008 on 11 July 1989. This maternity colony began vocalizing in the roost almost immediately at sunset. The first bat emerged 16 MAS and five more bats emerged by 22 MAS. After 22 MAS, emerging bats began to circle and reenter the roost. Vocalizations became more pronounced and radio-tagged female F138 emerged at 25 MAS. She circled the vicinity (<50 m) of the roost, landed on the roost tree near the roost site six minutes later, but did not reenter the roost. By 36 MAS we were no longer able to distinguish between newly emerging bats and bats that had already exited, circled the roost, reentered, and reemerged. Pronounced vocalizations could still be heard within the roost by darkness (43 MAS). By this time, radio-tagged female F138 had left the vicinity of the roost and was headed in a southeasterly direction toward her foraging area.

DISCUSSION

Aldridge and Brigham (1988) demonstrated that increases ≥5% of body mass of bats reduced their maneuverability and foraging efficiency and increased energy costs, but their findings did not reveal any potential effects of increased body mass on roost selection. We concede that decreased maneuverability and foraging efficiency of radio-tagged *M. sodalis* may force them to forage in less cluttered sites than the sites used by nonradio-tagged bats. Despite possible alterations in foraging behavior and the selection of foraging sites, we assumed that roost selection by radio-tagged *M. sodalis* did not deviate substantially from that of nonradio-tagged bats. We observed sufficient numbers of nonradio-tagged roosting *M. sodalis* together with radio-tagged bats to support this assumption.

The ability of *M. sodalis* to forage while carrying transmitters ranging in weight from 0.76 to 0.82 g (10-15% mean body weight) has been established by this study, but we did not ascertain how such a sudden increase in body weight affected foraging success. Male M462 was recaptured and weighed after radio-tracking his foraging activities for nine nights; he had maintained his weight exactly since his capture on 17 June 1987. Juvenile male M721 also maintained his weight after eight nights of radio-attachment.

Our data make clear that *M. sodalis* selected a wide range of roost sites. Sex, age, and reproductive groups showed no significant differences ($P \geq 0.1$) between species they selected as roost trees but selections were limited to certain species. Although at least 19 species of dead trees were identified within the Fishhook Creek study area, only ten species were used by *M. sodalis*. We have shown that *P. deltoides, Q. rubra, Q. stellata, Q. imbricaria, C. ovata, C. cordiformis,* and *U. rubra* possess morphological characteristics that make them highly suitable roost sites for *M. sodalis*. Senescent, severely injured (e.g., lightning-struck), or dead portions of these species possess bark that is tenacious (although length of persistence varies greatly according to species) and springs away from the trunk upon drying. Living *C. ovata* produces long strips of loosened but very persistent outer bark that allows some bats (although fewer in number) to find adequate shelter. Such species as *Acer negundo* (box elder), *Betula nigra* (river birch), *Fraxinus americana* (white ash), *Fraxinus pennsylvanica* (green ash), *Juglans nigra* (black walnut), *Prunus serotina* (wild black cherry), and *Robinia pseudoacacia* (black locust) were not used as roosts by *M. sodalis* during this study.

Humphrey *et al.* (1977) compared the thermoregulatory characteristics of an *M. sodalis* roost site beneath the bark of a dead *C. cordiformis* to the roosting spaces beneath the naturally exfoliating bark of a living *C. ovata*. We agree with Humphrey *et al.* (1977) that certain species of living trees are essential as alternate roosts during wet and/or cool weather or other unfavorable environmental conditions. Tree cavities or hollow bole portions of trunks and limbs also provide some suitable roost sites for *M. sodalis*. Although pregnant and lactating bats roosted in cavities for short periods of time, no maternity colonies were discovered in cavities during this study. Pregnant bats may use cavities as transient roosts or as gathering (staging) sites in early spring until suitable bark roosts, sheltering other *M. sodalis*, are located.

We consider optimal roost sites to occur beneath the bark of dead trees with adequate spaces to allow for air circulation and bat movement. Roost sites (e.g., 903, 915) exposed to intense solar radiation during mid-summer often exceed potentially lethal temperatures and are considered unsuitable for roosting *M. sodalis*. These same sites, however, may be entirely suitable when warmed more moderately by the sun in spring and early summer (April through June). Trees shaded from intense solar radiation and adequately ventilated also may be suitable as roost sites throughout the spring and summer.

Our data indicate that *M. sodalis* have strong site attachments to summer foraging and roosting habitats in Fishhook Creek and adjacent watersheds. As stated by Humphrey *et al.* (1977), traditional summer homes are essential to the reproductive success of local populations. The return of female F083 to Fishhook Creek to bear her young two years after she (known as juvenile F122 in 1986) was born there documents multiple summer fidelity in this species. Several males were also recaptured at Fishhook Creek in subsequent summers. Some roosts were used by *M. sodalis* during successive summers, further demonstrating their significance as traditional roosts. If these traditional roosts are not available, adult females are faced with finding suitable maternity sites at a time when they are already stressed from the rigors of hibernation, migration, and the increased energy costs of pregnancy.

The spatial relationships of roost trees to roads (paved or unpaved) and streams (perennial or intermittent) may predetermine their suitability as roost sites. Colonial (>5 bats) maternity roosts occupied by pregnant or lactating adult females occurred at least 450 m (mean = 1,488 m) from paved roads. The roost (910) nearest a paved road, 95 m from Illinois Route 104, was used on only two occasions by a nomadic male. Roosts were generally close (mean = 141 m; n = 56) to intermittent streams; however, they were farther from perennial streams (mean = 1097 m; n = 56) than we expected to find them. Two colonial maternity roosts were within 37 m of a perennial stream but the remaining six colonial roosts occurred at least 285 m away. Although riparian habitats represent a biologically significant component of the domain of *M. sodalis*, our data indicate that the selection of maternity roosts was not limited to riparian habitats. Reproductively active adult females are willing to travel up to 2.5 km from their roosts to reach foraging areas nearer perennial streams.

Humphrey *et al.* (1977) noted that any given roost (dead tree) may be habitable for only a short time (6 to 8 years), even if destruction by humans is excluded. Although information on the natural attrition of the roosts we studied is limited to four years, our data indicate that the life expectancy of some roosts may be much shorter. For example, *Ulmus rubra* were used frequently (n = 9) as roosts at Fishhook Creek, but none of seven original roost sites was available by the second summer following discovery and only one of the two remaining sites remained available after one summer. Three of these nine roost trees had fallen by the second summer. Conversely, two of the original nine *Quercus rubra* roost sites, used almost exclusively by reproductively active females and their young, were lost by the first summer and two more by the second summer following discovery. A high degree of loose bark retention was observed for other dead *Quercus* sp. and *Carya* sp. *Populus deltoides* often provides excellent roost sites, particularly for reproductively active adult females, but the loss of three of the four original roost sites only one year following their discovery suggests the precarious nature of roosts established in this species.

Mist netting and radio-tracking conducted simultaneously at Fishhook Creek revealed that *M. sodalis* subsequently avoided sites where they were netted. Disturbance of roosts so severe as to cause bats to flee could mean that they would not return to the disturbed roost. For example, post-lactating F342 roosted in *Q. rubra* 915 for three consecutive days until she was disturbed by the placement of a thermocouple probe in the roost. She abandoned this roost and moved to *Populus deltoides* 917, further (>3.5 km) away from her preferred foraging area. Although she did not return to roost 915, she returned to roost 917 after her nightly foraging bouts for at least three consecutive days. Bats captured away from their roost and radio-tagged returned repeatedly to their roosts if they were undisturbed at the roost.

Prior to this study, the majority of *M. sodalis* roosts were discovered only after the roost had been destroyed. Tree removal, either for harvest or land clearing (i.e., agriculture, utility and transportation rights-of-way), has been the most direct threat to *M. sodalis* summer roosts. The selective harvest of living trees, however, need not endanger summer roosts. Timber harvest activities within the Fishhook Creek study area did not directly affect known roosts or discourage bats from foraging in the harvested area. Noise and exhaust emissions from machinery could potentially disturb colonies of roosting bats, but such disturbances would probably have to be severe to cause roost abandonment. Accelerated bark sloughage or complete windfall of the roost tree may indirectly result from harvesting if the trees become more exposed to environmental rigors (e.g., rain, wind). Another indirect impact of harvesting may be increased solar heating due the to lack of shading. As a consequence, the microclimate of the roost may become unsuitable.

As is the case with other species of bats in the temperate zone (Kunz 1973; Tuttle 1975; Vaughan and O'Shea 1976), a variety of summer roosts is crucial to the reproductive success of *M. sodalis*. Its selection of roost sites is governed by the availability of natural structures, primarily dead trees with loose bark. The suitability of a site is determined by its quality: the quantity of loose bark, its ability to provide protection from the external environment, and its relationship to roads, streams, and foraging areas. Equally important is the availability of alternate roosts (i.e., *Carya ovata*) in close proximity to maternity roosts. If alternate sites are unavailable, unseasonably cool weather in spring may delay embryonic development. In early autumn, juvenile mortality may be increased if cool weather persists and no alternate site is available. Competition for acceptable maternity roost sites may be critical to the reproductive success of *M. sodalis* populations if roosts are limited.

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APPENDIX

Photographs of selected roost trees

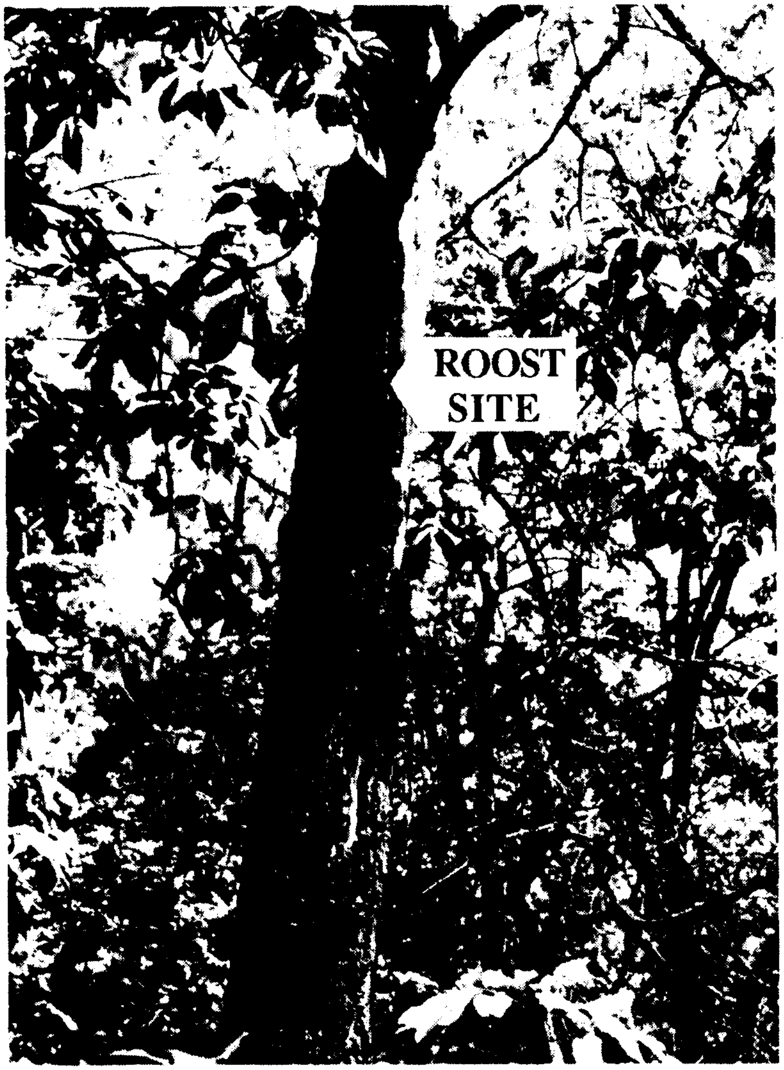

Figure A-1. *Quercus rubra* roost 901

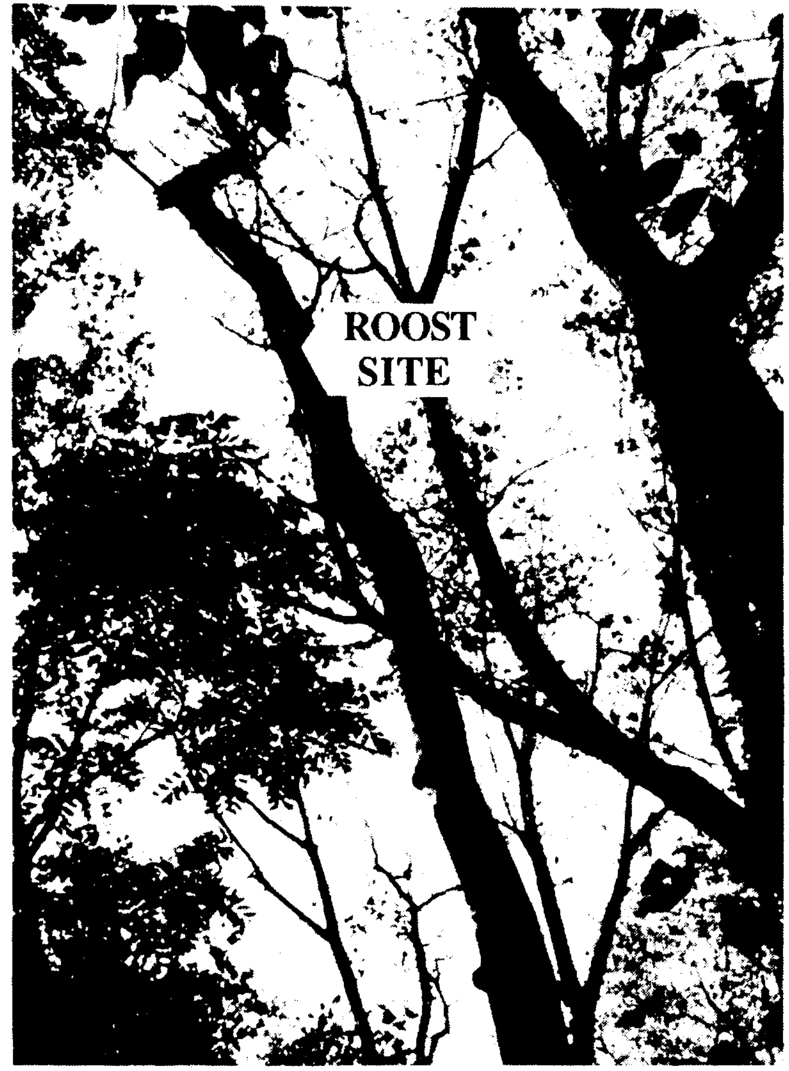

Figure A-2. *Populus deltoides* roost 902

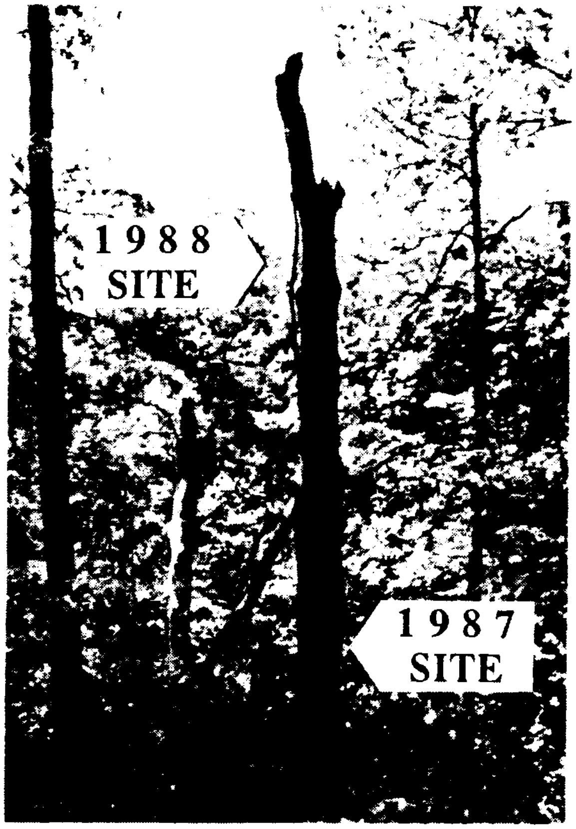

Figure A-3. *Quercus rubra* roost 903

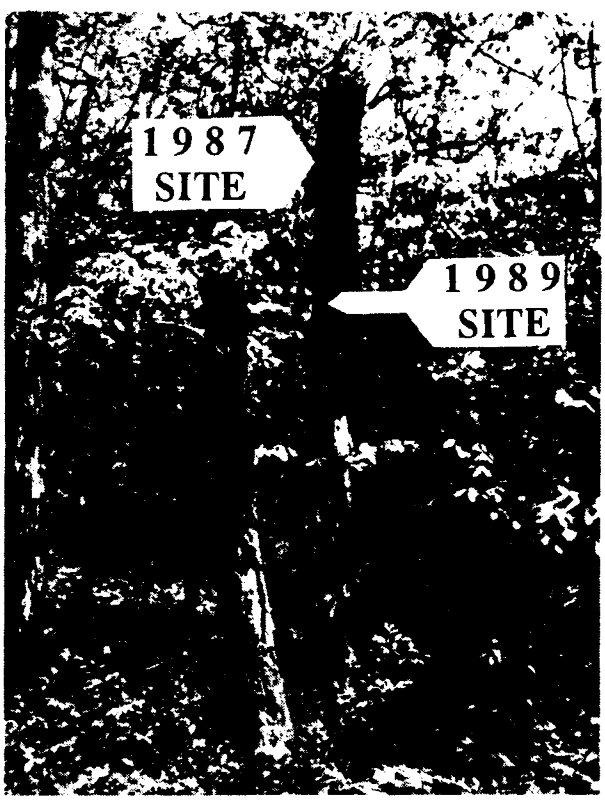

Figure A-4. *Quercus stellata* roost 905

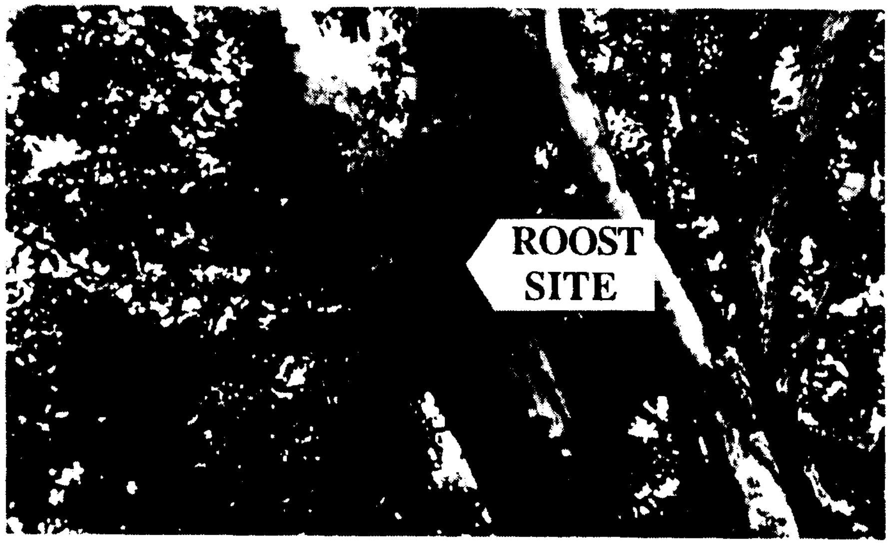

Figure A-5. *Ulmus rubra* roost 906

Figure A-6. *Quercus rubra* roost 915

Figure A-7. *Carya ovata* roost 920

Figure A-8. *Acer saccharinum* roost 924

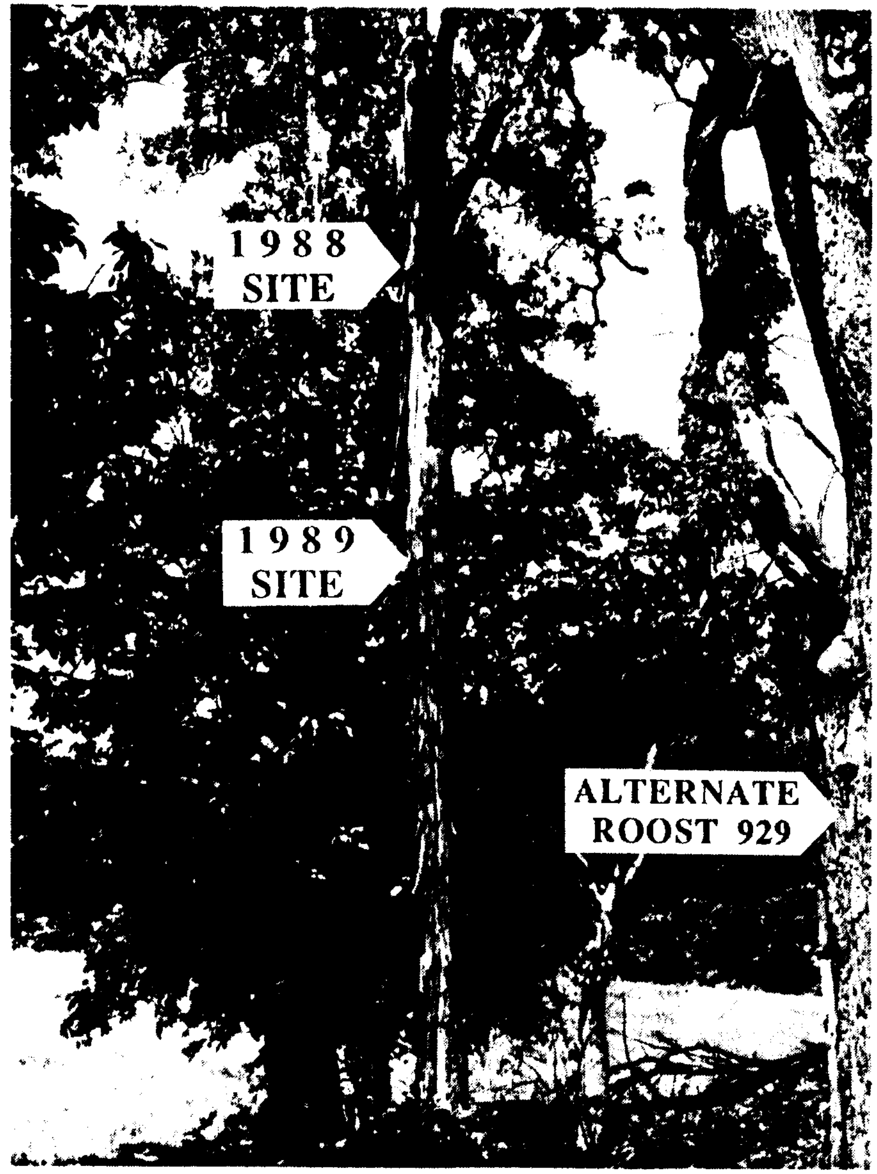

Figure A-9. *Carya ovata* roost 925 and *Quercus stellata* alternate roost 929